Invehicle Safety Advisory and Warning System (IVSAWS)

Volume V: Appendixes L Through V (Reference Materials)

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Invehicle Safety Advisory and Warning System (IVSAWS),

Volume V: Appendixes L Through V (Reference Materials)

U.S. Department of Transportation
Federal Highway Administration

Research and Development
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101-2296

FOREWORD

This report presents the results of a comprehensive study to identify candidate advisory, safety, and hazard situations where motorists would benefit from an Invehicle Safety Advisory and Warning System (IVSAWS). Functional specifications are also provided in sufficient detail to desciibe how these functions could be gradually incorporated into existing and future automotive vehicles. The IVSAWS, designed for rural, urban, and secondary roads, uses a proposed communication architecture based on transmitters placed on roadside signs and at roadway hazards to communicate with approaching vehicles equipped with IVSAWS invehicle radio receivers. This study will be of interest to transportation planners and engineers involved in motorist advisory and emergency communication systems.

Sufficient copies of the study are being distributed by the FHWA Bulletin to provide a minimum of two copies to each FHWA regional and division office, and five copies to each State highway agency. Direct distribution is being made to division offices.

Lyle Saxton
Director, Office of Safety and Traffic
Operations Research and Development

NOTICE

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16. Abstract

The Invehicle Safety Advisory and Warning System (IVSAWS) is a Federal Highway Administration effort to develop a nationwide vehicular information system that provides drivers with advance, supplemental notification of dangerous road conditions using electronic warning zones with precise areas of coverage. The research study investigated techniques to provide drivers with advance notice of safety advisories and hazard warnings so drivers can take appropriate actions. The technical portion of the study identified applicable hazard scenarios, investigated possible system benefits, derived functional requirements, defined a communication architecture, and made recommendations to implement the system.

This volume is the fifth in a series. The other volumes in the series are:

FHWA-RD-94-061	Volume I:	Executive Summary
FHWA-RD-94-190	Volume II:	Final Report
FHWA-RD-94-191	Volume III:	Appendixes A Through H (Reference Materials)
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yard	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in2	square inches	645.2	square millimeters	mm²
ft2	square feet	0.093	square meters	m2
yd2	square yards	0.836	square maters	m2
ac	acres	0.405	hectares	ha
mi2	squere mites	2.59	square kilometers	km2
		VOLUME		
ft oz	fluid ounces	29.57	milliliters	mL
gal	gallon	3.765	liters	L
ft3	cubic feet	0.026	cubit meters	m2
yd2	cubic yards	0.765	cubic meters	m3

NOTE: Volumes greater than looo I shall be shown in m3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	26.35	grams	g
lb	pounds	9.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or *metric ton)	Mg (or "t")
		TEMPERATURE (exact)		
oF	Fahrenheit temperature	5(F-32)/9 or (F-32/1.8)	Celcius temperature	oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	ix
ft	foot-Lamberts	3.426	candela/m2	cd/m2'
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbi/in2	poundforce per square inch	6.69	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By
	LENGTH	
mm	millimeters	0.039
m	meters	3.26
m	meters	1.09
km	kilometers	0.621
	AREA	
mm	square millimeters	0.0016
m2	square meters	10.764
m2	square meters	1.195
ha	hectares	2.47
km2	square kilometers	0.366
	VOLUME	
mL	milliliters	0.034
L	liters	0.264
m3	cubic meters	35.71
m3	cubic meters	1.307
	MASS	
g	grams	0.035
kg	kilograms	2.292
Mg (or "t"	megagrams (or 'metric ton.)	1.193
	TEMPERATURE (exact)	
oC	Celcius temperature	1.8C + 32
	ILLUMINATION	
lux	lux	0.0929
cd/m2	candela/m2	0.2919
	FORCE and PRESSURE or STRESS	
N	newtons	0.225
kPa	kilopascals	0.145

SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380

TABLE OF CONTENTS

Section	Page
VOLUME I:	
EXECUTIVE SUMMARY - IVSAWS FINAL REPORT	1
REFERENCES	23
VOLUME II:	
CHAPTER 1. INTRODUCTION	25
CHAPTER 2. HAZARD SCENARIO IDENTIFICATION AND SIGNALING PRESENTATION ANALYSIS	29
CHAPTER 3. RESULTS OF THE DRIVER ALERT WARNING SYSTEM MOCKUP TESTING AND EVALUATION	51
CHAPTER 4. FREQUENCY BAND SELECTION ISSUES	69
CHAPTER 5. DRIVER ALERT DISTANCE RANGE DETERMINATION	83
CHAPTER 6. GENERAL PUBLIC AND DEPLOYMENT COMMUNITY SURVEYS	91
CHAPTER 7. THE PRACTICALITY OF IVSAWS DEPLOYMENT BY RAILROAD OPERATORS	111
CHAPTER 8. FUNCTIONAL DEFINITION	125
CHAPTER 9. SYSTEM ARCHITECTURE ANALYSIS	137
CHAPTER 10. NARROWBAND GPS ARCHITECTURE WAVEFORM DESIGN	179
CHAPTER 11. NARROWBAND GPS ARCHITECTURE PERFORMANCE ANALYSIS	197
CHAPTER 12. OPERATIONS CENTER IMPLEMENTATION ANALYSIS	225
CHAPTER 13. VEHICLE RETROFIT ANALYSIS	237
CHAPTER 14. ANTENNA PERFORMANCE ANALYSIS	247
REFERENCES	253
VOLUME III	
APPENDIX'A: WORKPLAN FOR THE IN VEHICLE SAFETY ADVISORY AND WARNING SYSTEM (IVSAWS)	A-l
APPENDIX B: IVSAWS ENGINEERING CHANGE PROPOSAL 3 (ECP-003) OVERVIEW	B-l
APPENDIX C: INVEHICLE SAFETY ADVISORY AND WARNING SYSTEMS, TASK B — FINAL REPORT	C-l
APPENDIX D: DRIVER ALERT DISTANCE ANALYSIS SCENARIO SELECTION	D-l

TABLE OF CONTENTS
(continued)

Section **Page**

APPENDIX E: DRIVER ALERT DISTANCE ANALYSIS .... E-l

APPENDIX F: COMMUNICATION PATH GEOMETRY ANALYSIS F-1

APPENDIX G: INVEHICLE SAFETY ADVISORY AND WARNING SYSTEM (IVSAWS) TASK E REPORT, RESULTS OF THE DRIVER ALERT WARNING SYSTEM DESIGN MOCKUP TESTING AND EVALUATION .... G-l

APPENDIX H: PROPOSAL FOR THE INVEHCLE ADVISORY AND WARNING SYSTEM (IVSAWS) .... H-l

VOLUME IV:

APPENDIX I: INVEHICLE SAFETY ADIVSORY AND WARNING SYSTEM (IVSAWS) COMMUNICATIONS TECHNOLOGY SELECTION I-1

APPENDIX J: ENGINEERING CHANGE PROPOSAL 2 REPORT, IVSAWS COMMUNICATION SUBSYSTEM ARCHITECTURE TRADEOFFS .... J-l

APPENDIX K: ASSESSMENT OF IVSAWS DEPLOYMENT PRACICALITY .... K-l

VOLUME V:

APPENDIX L: RAILROAD INDUSTRY INTERVIEW RESULTS .... L-l

APPENDIX M: MARKET-POTENTIAL ASSESSMENT OF IVSAWS RESEARCH AMONG THE GENERAL PUBLIC AND DEPLOYMENT PROFESSIONALS .... M-l

APPENDIX N: IVSAWS TASK B, SUBTASK 4 REPORT (ENGINEERING CHANGE PROPOSAL 3, OPTION AA) FUNCTIONAL DEFINITION N-1

APPENDIX O: IVSAWS SYSTEM ARCHITECTURE ANALYSIS .... O-l

APPENDIX P: IVSAWS WAVEFORM DESIGN #l (NARROWBAND COMMUNICATION WITH GPS AOC CONTROL) .... P-l

APPENDIX Q: IVSAWS WAVEFORM DESIGN #2 (RBDS COMMUNICATION WITH COVERAGE CONTROL) .... Q-l

APPENDIX R: IVSAWS PERFORMANCE ANALYSIS .... R-l

APPENDIX S: IVSAWS IMPLEMENTATION ANALYSIS S-1

APPENDIX T: IVSAWS RETROFIT ANALYSIS .... T-l

APPENDIX U: IVSAWS ANTENNA PERFORMANCE ANALYSIS .... U-l

APPENDIX V: DESIGN CONCEPT FOR AN INVEHICLE SAFETY ADVISORY AND WARNING SYSTEM (IVSAWS) .... V-l

VOLUME I
LIST OF FIGURES

Figure **Page**

Figure		Page
1.	System concept	1
2.	IVSAWS program road map	3
3.	Preference index by subject group	12
4.	Link losses in flat terrain	14
5.	Link losses in heavy foliage	14
6.	Scenario issues	15
7.	Customer-requested features	16

VOLUME I
LIST OF TABLES

Table **Page**

Table		Page
1.	Metropolitan areas by population	10
2.	Combined ranking of scenarios	11
3.	Driver alert distances	14
4.	Functional characteristics of the communication architecture candidates	20
5.	Functional characteristics of the geolocation architecture candidates	20
6.	System architecture comparisons	21

VOLUME II
LIST OF FIGURES

Figure		Page
1.	IVSAWS original task flow	26
2.	IVSAWS program flowchart (ECP-003)	27
3.	Task B, subtask 6 technical approach	41
4.	Emergency vehicle situation with/without warning	44
5.	Mockup construction and dimensions	55
6.	Current SAE driver packaging model	59
7.	Preference index by subject group	62
8.	Mean rank and standard deviation of signal options	63
9.	Preference by age group	64
10.	Mean preference by subject group	65
11.	Preference index for female population group	66
12.	Task flow for IVSAWS frequency band selection	69
13.	Link losses for geometry A - straight road over flat surface	74
14.	Link losses for geometry B - curved highway through trees	74
15.	Link losses for geometry C - highway through rolling hills	75
16.	Link losses for geometry D - curved road with interleaving mountains	75
17.	U.S. frequency usage in the 410-MHz to 470-MHz band	78
18.	Site locations of AN/fPS-115 PAVE PAWS	79
19.	Driver alert distance time line	84
20.	Geometry A link margins versus vehicle speed and hazard avoidance maneuver	88
21.	Geometry B link margins versus vehicle speed and hazard avoidance maneuver	88
22.	Geometry C link margins versus vehicle speed and hazard avoidance maneuver	89
23.	Geometry D link margins versus vehicle speed and hazard avoidance maneuver	89

VOLUME II
LIST OF FIGURES
(continued)

Figure		Page
24.	Preference index by subject group	94
25.	Percentage of Americans living in urban areas	95
26.	Scenario with alert discrimination . accident on overpass road	100
27.	Scenario with alert discrimination - accident on parellel access road	100
28.	Warning-time attribute importance	101
29.	Warning-distance attribute importance	101
30.	False-alarm attribute importance	102
31.	Maximum purchase price acceptable to general public for invehicle unit	102
32.	Deployment-time attribute importance	104
33.	Maximum purchase price acceptable to deployment agencies for invehicle unit	105
34.	General QFD design flowchart	128
35.	IVSAWS QFD design flowchart	129
36.	Requirements model structure	130
37.	Nested layers of functional definition	132
38.	IVSAWS system-level function cost-effectiveness boundaries	133
39.	LPHAR block diagram	139
40.	AHAR block diagram	140
41.	RBDS/SCA block diagram	142
42.	SAP block diagram	146
43.	T-net block diagram	148
44.	220-MHz to 222-MHz band	150
45.	IVSAWS exclusive use in the 220-MHz to 222-MHz band	150
46.	Cellular block diagram	152

VOLUME II

LIST OF FIGURES (continued)

Figure		**Page**
47.	Impulse block diagram	155
48.	Packet radio block diagram	157
49.	Trunk radio block diagram	159
50.	Shared-channel block diagram	161
51.	Microwave block diagram	163
52.	Terrapin's PINS block diagram	167
53.	GPS block diagram	168
54.	Loran-C block diagram	170
55.	Constraint length seven half-rate convolutional encoder	180
56.	B/4 shifted, differentially encoded QPSK constellation	181
57.	Modulation process using raised-cosine filtering	182
58.	IVSAWS emissions mask	183
59.	Frame structure	185
60.	The Traverse Mercator Projection (the cylinder is chosen slightly smaller than the earth to reduce distortion to a minimum between angles and distance on the earth as compared to the same two quantities on the map)	187
61.	UTM 6o-wide standard zones (each zone has as its east and west limits a meridian of longitude, and one central meridian for a 6" by 8" N-S area determined by the column (zone) and row (alphabetic) UTM terms, e.g., the shaded area shown here is designated as 30P	188
62.	Grid-square designators (the letters and numbers indicate grid-zone designation, 100 000-m square identification, and grid coordinates of the point expressed to the desired accuracy)	188
63.	Direction indicator bit assignments	189
64.	Continue message structure	193
65.	Free-text message structure	193
66.	Delete message structure	194

VOLUME II
LIST OF FIGURES (continued)

Figure		Page
67.	System time and GPS correction message structure	194
68.	AOC extention message	194
69.	Bandwidth power efficiency plane (coherent demodulation, Pb(e) = 10-5)	198
70.	Relative complexity of candidate modulation schemes	199
71.	Rayleigh fading probability at 220 MHz	201
72.	IVSAWS B/4-shifted DQPSK performance (differentially coherent demodulation)	203
73.	IVSAWS preamble auto-correlation function	205
74.	Non-coherent combining losses (non-coherent combining losses as a function of pulses combined and the per pulse signal-to-noise ratio, Naval Research Laboratory Report 8025)	207
75.	Detection and false alarm performance (required signal-to-noise ratio as a function of probability of detection to achieve a particular probability of false alarm, Naval Research Laboratory Report 11930)	208
76.	DQPSK BER performance over a Rayleigh fading channel	210
77.	Relationship between average channel bit error rate (Pcb) and the BER at the output of a hard-decision Viterbi decoder (K = constraint length, R = code rate)	212
78.	Predicted IVSAWS base station and mobile unit communication ranges	219
79.	Base station layout over smooth terrain (four channels are sufficient to provide continuous coverage while maintaining an acceptable co-channel signal-to-interference (S/I) margin)	221
80.	Narrowband communication - GPS AOC control system	226
81.	RBDS - GPS/terrapin AOC control system architecture	227
82.	IOC block diagram	229
83.	IOC hardware diagram	232

VOLUME II
LIST OF FIGURES
(continued)

Figure		Page
84.	IOC base station transmitter links using microwave repeaters	235
85.	Invehicle block diagram	238
86.	Invehicle information flow	238
87.	Invehicle retrofit diagram, option 1	239
88.	Invehicle retrofit diagram, option 2	241
89.	Vehicle antenna candidates	247
90.	Gain degradation of a 762-mm monopole tuned to 220 MHz as a function of length variation	249
91.	VHF/UHF diplexer and GPS link	250
92.	Calculated elevation pattern of an FM monopole @ 222 MHz	251
93.	Measured elevation pattern of a cellular monopole @ 250 MHz	251

VOLUME II
LIST OF TABLES

Table		Page
1.	Rankings of possible IVSAWS applications	36
2.	Tentative IVSAWS alerting messages	46
3.	Alerting-message design guideline sources	47
4.	Preliminary requirement for frequency band search	71
5.	Candidate IVSAWS frequency bands	71
6.	Terrain geometry selection	72
7.	Hazard avoidance maneuver distances	85
8.	Decision sight distances	85
9.	Driver alert distances	87
10.	Ranking of scenarios	93
11.	Architecture tradeoff summary	94
12.	Urban areas by population	96
13.	Workshop ranking of scenarios	98
14.	Community classifications for indepth interviews	105
15.	Rankings of possible IVSAWS applications	109
16.	Combined list of deployment professionals and motorist requested features	109
17.	Class I railroads	115
18.	Communication architecture functional characteristic tradeoffs	165
19.	Communication architecture technology tradeoffs	166
20.	Frequency allocation	172
21.	Transmission capability	174
22.	Communication architecture transfer rate	175
23.	Error detection and recovery capability	177
24.	Differential phase code	180

VOLUME II
LIST OF TABLES
(continued)

Table		Page
25.	Alert types	184
26.	Allocations for alert duration	186
27.	Alert status	186
28.	Field allocations for zone location	189
29.	AOC shapes	190
30.	Message extension subfield contents	190
31.	Station ID, station health, and Z-count field structure	191
32.	Field structure for GPS correction	192
33.	Field allocations for system time	192
34.	Performance of candidate modulation schemes over a Rayleigh fading channel	201
35.	Noise power at receiver	210
36.	Terrain descriptions	217
37.	Extended Longley-Rice model parameters	218
38.	Performance of selected half-rate codes	220
39.	Fleet management systems	229
40.	Development software costs	230
41.	PC-based IOC hardware costs	232
42.	UNIX workstation-based IOC hardware costs	233
43.	IOC communication connections	233
44.	Base station hardware costs	235
45.	Cables and connections retrofit, option 1	242
46.	Cables and connections retrofit, option 2	242
47.	Baseline equipment costs	243
48.	Retrofit equipment and installation costs, option 1	243

VOLUME II
LIST OF TABLES
(continued)

Table		Page
49.	Retrofit equipment and installation costs, option 2	243
50.	Summary of antenna candidates	248

APPENDIX L:
RAILROAD INDUSTRY INTERVIEW RESULTS

This appendix contains the results of discussions held with representatives from a subset of railroad companies that could deploy the Invehicle Safety Advisory and Warning System (IVSAWS). The purpose of the discussions was to assess the deployment practicality of different IVSA WS system concepts that focused on the application of IVSA WS to reduce the frequency and severity of train-vehicle accidents at railroad grade crossings.

The Practicality of IVSAWS Deployment by Railroad Operators

INTRODUCTION

This report presents the results of discussions held with representatives from a subset of railroad companies that could deploy the In-Vehicle Safety Advisory and Warning System (IVSAWS). The purpose of the discussions was to assess the deployment practicality of different IVSAWS system concepts that focused on the application of IVSAWS to reduce the frequency and severity of train-vehicle accidents at railroad grade crossings. The meetings were a supplement to interviews held in 1992 with a diverse sampling of the postulated IVSAWS deployment community. The initial round of interviews included representatives from law enforcement agencies, fire departments, ambulance operators, road construction companies, and state transportation departments.

On July 15, 1993 the Federal Highway Administration ordered a subsequent round of interviews to be held exclusively with railroad companies. The following reasons were cited:

- railroad companies were underrepresented during the initial round of interviews
- the IVSAWS situation hierarchy development (Task B) identified the railroad grade crossing situation as a prime IVSAWS application candidate
- the FHWA's desire to field an IVSAWS prototype during the proposed Vehicle Proximity Alert System (VPAS) demonstrations requires a better understanding of locomotive electronics and the railroad industry's perspective regarding grade crossing technology.

From the perspective of those individuals and agencies that might be responsible for establishing the IVSAWS warning zones, deployment practicality can be evaluated using various criteria. For this study, the selected evaluation criteria were 1) the willingness of an agency or company to adopt IVSAWS, 2) compatibility of IVSAWS deployment procedures with existing operating procedures, 3) the amount of time and attention required for deployment tasks, 4) system cost, and 5) compatibility of IVSAWS-specific equipment with existing agency hardware and software. During the initial round of interviews it was found that the relative significance of the evaluation criteria is a function of the deployment agency. For example, law enforcement agencies focus on the amount of time and attention required for IVSAWS deployment tasks; the deployment of IVSAWS must not take longer than three to five seconds if the system is to be used at accident sites and during traffic stops. Road construction and road maintenance crews identified a low driver false alarm rate as being key to their acceptance of IVSAWS; drivers must believe they will encounter roadway workers when they receive an alert; otherwise, they will ignore the warning, thereby eliminating the additional protection IVSAWS could provide to the workers.

Conversely, the railroads concluded that a locomotive-based IVSAWS will need to be nearly autonomous and require little or no support from the locomotive engineer, thereby diminishing the significance of evaluation criteria that are operational in nature (2 and 3, above). In general, the primary barrier to railroad industry deployment of IVSAWS will be the reluctance of management to expose their companies to additional liability for train-vehicle collisions through introduction of a safety system for which they will be responsible. Moreover, unless mandated by law, IVSAWS deployment will only be possible if the railroad industry is convinced the system will reduce the size and number of court awards granted to individuals involved in train-vehicle accidents. System performance issues dominate system operation issues.

INTERVIEW PREPARATION

Preparation for the interviews consisted of the following four steps: identification of appropriate deployment agency interview candidates, initial phone contact with the candidates, distribution of an IVSAWS program overview package to interested candidates, second phone contact with interested candidates, and conduct of the interview.

All contacts were derived from the reference Jane's World Railways. The reference contains descriptions of all Class I railroads. The initial goal was to interview representatives from the six largest railroads in the United States. Initial phone contacts with perspective interviewees met with mixed results. With no previous exposure to IVSAWS, most contacts were generally non-committal and wanted more information prior to consenting to an interview. CSX and Santa Fe railroads recommended that IVSAWS discussions be held with the Association of American Railroads (AAR), not individual railroad companies. The AAR is a rail industry trade association. Membership includes all Class I (major) railroads operating in the Unites States. Following the lead, the AAR was contacted. Subsequently, two interviews were held with the Association.

The information package used to provide IVSAWS program background to prospective interviewees is included as Appendix A. It includes a cover letter, program overview, system concept diagrams, brief system concept descriptions, and identification of IVSAWS-locomotive interface issues.

INTERVIEW PROCEDURE

The following page shows the agenda for the interviews. After a brief IVSAWS overview, three IVSAWS concepts were presented. Then, each concept was evaluated. After the evaluations, the interviewees were asked to rank the system concepts with respect to overall deployment practicality. Finally, technical issues (e.g., IVSAWS-locomotive interface) were discussed. On average, the interviews lasted three hours.

AGENDA
IVSAWS OPERATIONAL CONCEPT EVALUATION

IVSAWS OVERVIEW	30 - 45 MINUTES
IVSAWS APPLICATION TO GRADE CROSSING SITUATION	30 MINUTES

- NON-INSTRUMENTED CROSSINGS
- INSTRUMENTED CROSSINGS
- PROBLEM CROSSINGS

OPEN DISCUSSION	AS REQUIRED

- GENERAL IMPRESSIONS / ACCEPTABILITY
- PERCEIVED PROBLEMS
- COST LIMITATIONS
- IDENTIFICATION OF PREFERRED APPROACH
- TECHNICAL AND OPERATIONAL ISSUES
  - GLOBAL POSITIONING SYSTEM (GPS) RECEIVER INTERFACE TO LOCOMOTIVE AND END-OF-TRAIN DEVICE
  - 220 - 222 MHZ TRANSCEIVER INTERFACE TO LOCOMOTIVE
  - 220 - 222 MHZ TRANSMITTER INTERFACE TO INSTRUMENTED CROSSING
  - 220 - 222 MHZ TRANSMITTER INTERFACE TO NON-INSTRUMENTED CROSSING
  - IVSAWS INSTALLATION AND MAINTENANCE
  - IVSAWS INITIALIZATION
- OTHER

SYSTEM CONCEPTS

Three rail-based IVSAWS concepts are described below. All involve the use of a locomotive-based transmitter and in-vehicle receiver. The primary difference between the concepts is the number of radios used to relay the warning message from the train to the driver (zero, one, or several).

The system concepts were defined as a group of events required to establish a RF warning zone that, when penetrated by IVSAWS-equipped vehicles, informs drivers that a train is at or approaching a grade crossing. At each step, the hardware and software required to support the operation was described.

System Concept 1

A locomotive-based IVSAWS projects warning zone around the train. See page A-4, Appendix A. This concept uses a locomotive-based GPS receiver to determine the position of the train. The IVSAWS uses this information to define an area of alert coverage (AOAC) around the train. The AOAC vertex coordinates are broadcast by a narrowband transmitter. The GPS receiver operates in differential mode to improve AOAC resolution and accuracy.

As an option, a database in the locomotive identifies the coordinates of grade crossings. Using this information, the IVSAWS projects the RF warning zone around the crossing, not the train.

Group of events:

- Event 1: An NSAWS base station (not shown on Figure 1) periodically transmits differential GPS psuedorange and range rate corrections. The corrections are received by IVSAWS receiver in locomotive which downloads the correction data to the GPS receiver. The corrections improve GPS accuracy to approximately +/- 5 meters.

- Event 2: The IVSAWS monitors the locomotive position using GPS (once per second position calculations). Successive measurements are used to calculate train velocity. Knowing train speed, train position, and length of train (downloaded prior to train movement) the locomotive's IVSAWS controller defines an area of alert coverage (AOAC) in front of and around the train. The AOAC extension in front of the train is a function of train speed. The AOAC definition is in the form of a set of vertex coordinates (Universal Transverse Mercator). The coordinates specify a polygon around the train.

Option Locomotive IVSAWS has access to a database which identifies the coordinates of each and every grade crossing (approx. 329,000 in US). As the train approaches a grade crossing, the AOAC is defined as a polygon around the grade crossing, not the train. The AOAC is broadcast until the train passes the crossing.

- Event 3: Every three seconds, the locomotive broadcasts AOAC definition, train velocity (speed and direction), train length, and locomotive position using an IVSAWS transmitter.

- Event 4: Vehicles equipped with IVSAWS monitor vehicle position using differential GPS.

- Event 5: Vehicles equipped with IVSAWS receivers continuously monitor the media for alert broadcasts, including broadcasts from trains. When an alert is received, the alert data is downloaded to a database, provided the vehicle is within the defined AOAC.

- Event 6: Every second, vehicular IVSAWS compare vehicle position to the set of AOACs stored in memory. If the vehicle is within an AOAC (and other checks are passed), a driver alert distance (DAD) is calculated. The DAD defines the vehicle-hazard separation at which the in-vehicle alert is to be generated. The DAD is a function of vehicle velocity, vehicle position, train position and train velocity. The DAD is calculated to provide a six to ten second warning (six to ten seconds before vehicle and train paths could intersect). When the vehicle reaches the DAD (it may change as the vehicle and train move), the driver is alerted.

System Concept 2

An IVSAWS warning unit located at a grade crossing projects an RF warning zone around the crossing. See page A-5, Appendix A. The warning zone is activated by a locomotive-based radio. The radio on the locomotive may or may not be an IVSAWS transceiver.

Group of events:

- Event 1: A crossing-based IVSAWS Warning Unit monitors the media for broadcasts by approaching trains. The warning units calculate the range and closing rate of an approaching train based upon information derived from the broadcasts.

- Event 2: When the train is a pre-determined number of seconds “in front” of the crossing (based upon train-crossing separation and train speed) the IVSAWS Warning Unit projects an RF warning zone around the crossing. The warning zone AOAC definition is in the form of a set of vertex coordinates (Universal Transverse Mercator). The coordinates specify a polygon around the crossing. Since the grade crossing is stationary, the vertex coordinates can be sited in during Warning Unit installation and be permanently stored in memory (no GPS receiver required).

- Event 3: Every three seconds, the Warning Unit broadcasts AOAC definition, train velocity (speed and direction), train length, and locomotive position using an IVSAWS transmitter.

- Events 4 through 6: Same as System Concept 1.

System Concept 3

Same as System Concept 2, except a network of radios is used to perform, train detection. See page A-6, Appendix A. This system concept is for use in adverse communication environments in which the communication range between the locomotive and warning unit is limited (e.g., tunnel “upstream” of crossing). The warning zone is still activated by a locomotive-based radio. Again, the radio on the locomotive may or may not be an IVSAWS transceiver. However, the activating signal is relayed through the network of radios to the crossing-based IVSAWS warning unit which projects an RF warning zone using an IVSAWS transmitter.

Group of events:

- Event 1: Warning unit monitors the media for locomotive broadcast information relayed to it through the network radios. The network radios calculate the range and closing rate of the approaching train based upon information derived from the broadcasts.

- Events 2 through 6: Same as System Concept 2.

INTERVIEWS

A total of seven interviews were conducted, five with railroad companies and two with the Association of American Railroads (AAR). The five railroads are all Class I (major) railroads. Table 1 provides a list all Class I railroads. Those companies interviewed are listed in italic.

Table 1. Class I Railroads.

Company	Miles of track operated	Gross revenue
Burlington Northern	23,088	$4,558,650,000
Union Pacific	20,261	$4,662,956,000
C S X	18,854	$4,336,375,000
Norfolk Southern	*14,721*	*$3,653,971,000*
Conrail	12,454	$3,136,548,000
Southern Pacific	12,143	$2,348,602,000
Atchison, Topeka and Santa Fe	9,639	$2,153,535,000
Amtrak	*not available*	*$1,359,000,000*
Canadian Pacific (Soo & D&H)	*7,445*	*not available*
Chicago and Northwestern	5,573	$803,033,000
Illinois Central	2,766	$549,728,000
Denver and Rio Grande Western	2,246	$321,669,000
Kansas City Southern	1,682	$322,245,000
Grand Trunk Western	925	$270,436,000
Florida East Coast	442	$138,212,000

Union Pacific Railroad

Place:	Omaha, Nebraska	
Date:	August 18, 1993	
Railroad Representatives:	Michael Deatherage	Director, Safety and Occupational Health
	David McCord	Manager, Electrical Design
	Harry Pitner	Manager, Locomotive Planning and Standards

Union Pacific representatives were generally skeptical of all three IVSAWS system concepts. Their major concern was system reliability. Constant system self testing should be employed such that there is no chance of an undetected system fault. Mr Pitner identified the locomotive as a very severe operational environment due to temperature extremes, vibration, and dirt. He recommended that IVSAWS components installed in locomotives be built to military environmental/reliability standards.

A major implication of system reliability is responsibility for accidents at crossings protected by IVSAWS. In order for Union Pacific to embrace an IVSAWS concept, the representatives felt the Government must immune railroads from lawsuits involving IVSAWS. They recommended an approach similar to that used in Europe: If a vehicle hits a train (or vice versa), the driver of the vehicle receives a traffic citation (if he/she is still alive).

Mr. Deatherage noted that the majority of train-vehicle accidents occur when the train is traveling less than 30 mph. Many accidents occur under switching conditions when the train is reversing direction. The “busiest section of track in the world” is between Given Nebraska and North Platte, South Dakota. On average, 100 trains per day travel this segment at an average speed of 40 mph. This level of traffic could be used to set an upper limit on battery or solar panel capacity required to support trackside IVSAWS installations at crossings without power sources. David McCord noted that "solar panels work well" in similar rail applications.

The representatives ranked the system concepts in the following order:

1. System Concept 2. The representative thought this concept would be the most reliable, especially at crossing already equipped with train detection circuits. The IVSAWS warning unit could read the train detect control output to activate/deactivate the transmitter. It was mentioned that train detection circuits cost $20,000, installed. Full crossing instrumentation, including lights, bells, and/or gates, cost between $30,000 and $100,000 per crossing, depending on the level of instrumentation.

2. System Concept 1. The representatives thought this concept would be less reliable than System Concept 2 due to the amount and complexity of the hardware installed in the train (two receivers, one transmitter, one controller). Also, there is no way to verify proper system operation since the link with the vehicles is open loop. Union Pacific did recognize a cost advantage to this concept since no instrumentation is required at crossings.

Option: The idea of storing a crossing location database onboard locomotives was not well received. Accurate maintenance of such a database was thought to be nearly impossible. If implemented, the database would need to be national (all 320,000 crossings) since locomotives from one company often use another company's track and locomotive lease agreements are common. Locomotives tend to migrate over large distances. Additionally, reprogramming of the database via a radio link is "a must."

3. System Concept 3. This concept was rejected due to the amount of hardware involved. High cost and low reliability were cited as concerns.

Some of the discussion centered on the use of end-of-train devices (EOTs) to determine the length of the train. The possibility of integrating a GPS receiver with an EOT was examined. Since the EOT periodically communicates with the lead locomotive, end of train position data from the GPS receiver could be relayed to the IVSAWS controller over this communication link. Union Pacific representatives had the following criticisms:

- EOTs are not universally deployed, nor are they configured the same.
- EOT-locomotive communication is unreliable.
- EOTs are mounted on the knuckle of the last car. A weight limit of 35 pounds is imposed. Most EOTs are already at the 35 pound limit.
- EOTs are battery operated. A GPS receiver and controller would reduce already limited battery life.

Instead, it was recommended that train length be a programmable input to IVSAWS, downloaded prior to train movement by the lead locomotive engineer.

Association of American Railroads - Transportation Test Center

Place:	Pueblo, Colorado	
Date:	August 19,1993	
Railroad Representatives:	Scott Gage	Test Engineer
	Warren Peterson	General Manager

The primary purpose of the interview with AAR was to evaluate the Pueblo Transportation Test Center (TTC) with respect to test facility support requirements for the proposed Vehicle Proximity Alert System (VPAS) demonstrations.

The requirements are outlined below:

1. Equipment Requirements

a. Train track with an instrumented multi-track (at least two) grade crossing. Instrumentation must provide digital “train present” control output which can be connected to prototype VPAS hardware. Crossing must have a 12 VDC power supply (10 Amps, minimum). Track must be long enough to support train speeds of 40 mph. VPAS prototype testing will last 8 - 12 weeks (continuous, sometime during July - October, 1994) including initial setup and human factors testing.

b. Two trains. Each train must be long enough two verify operation of VPAS end-of-train detection functions (10 cars minimum). Locomotives must have space to install prototype VPAS hardware (e.g., computer, power converter, transceiver, antennas). Locomotive must provide 12 VDC power. Trains will be required for 8 - 12 weeks.

c. Office space for four engineers (two Hughes, 1 FHWA, 1 VPAS demonstration contractor) with phones, copy machine, and FAX.

d. Lab space with a minimum of two large test benches with access to AC power.

e. Building or enclosure with AC power and access to antenna mast (> 100 feet) for housing base station transmitter.

f. Test vehicles. Two vans will be required to serve as test vehicles. One other support van will be required.

g. Secure storage for VPAS hardware and test equipment (approx. 300 square feet).

h. Machine shop access for fabrication of equipment mounts and brackets.

2. Time and materials

a. Support personnel. Hughes, demonstration contractors, and the FHWA will provide personnel to operate/maintain VPAS equipment and collect test data. AAR will provide all other support personnel (e.g., locomotive engineers, locomotive technicians).

b. Non-durable materials. Gas, locomotive fuel, mounting brackets, wire, etc. Also includes insurance, if required.

c. AAR will provide personnel to assist in development of test scripts for distribution to demonstrators. AAR will evaluate and order changes to demonstrator test plans.

d. AAR will assist FHWA and FRA with VPAS prototype evaluations. AAR will document evaluations.

Based upon discussions with Scott Gage and Warren Peterson, and after a two hour site survey, it was determined that the TTC will meet VPAS demonstration requirements. Photographs taken during the survey follow. Warren Peterson, TTC General Manager, was asked to submit a bid in support of the demonstration. He deferred submission of a proposal, pending approval by the AAR’s Washington, D.C. office. He recommended that Hughes visit the AAR’s Washington office during the East Coast segment of the railroad company interviews in order to expedite AAR approval. His recommendation was followed.

Burlington Northern Railroad (BN)

Place:	Fort Worth, Texas	
Date:	August 20,1993	
Railroad Representatives:	Les Bahls	Asst. Chief Engineer, Telecommunications
	Lynn Garrison	Sr. Research Engineer, Research and Development
	George Hsu	Sr. Research Engineer, Research and Development
	Roger Nelson	Vice President, Field Safety
	Ron Newmann	Director, Research and Development

BN representatives noted that approximately 500 deaths per year are attributable to grade crossing accidents, therefore utilization of IVSAWS to inform drivers of train proximity has strong merit potential.

The representatives ranked the system concepts in the following order:

1. System Concept 2. BN preferred this concept due to its compatibility with currently instrumented crossings. Roger Nelson mentioned that fifty percent of grade crossing accidents occur at instrumented crossings. Ideally, IVSAWS would replace all other forms of instrumentation. That is, every other grade crossing system would be eliminated. If so, some sort "intervention" might be required to place liability for accidents on drivers. This would open the door for an off-the-shelf "dash mount" IVSAWS market since drivers would want to protect themselves. If automobile manufactures were required by law to install IVSAWS units in vehicles, they might insist upon the installation of automotive "black boxes".

2. System Concept 1. This concept was not favored since no interface between IVSAWS and existing track-based train detection circuits is supported. The representatives were also concerned with this concept's potential for false driver alerts.

option: Projection of the IVSAWS warning zone around the grade crossing was preferred to projection around the train. False driver alerts would be minimized. Storing a crossing-location database onboard locomotives "is not that big of a problem" since the makeup of crossings is not dynamic. The database would need to be 1) national, 2) maintained by the FRA and 3) automatically updated within locomotives when changes occur. The FRA currently correlates every crossing to a unique DOT number, however the database does not include the crossing lat/long position required by IVSAWS. The updates could be performed using the developmental Automatic Train Control System (ATCS) , a trackside transponder-based system, which should be deployed by the end this decade. ATCS RF communication is projected to operate between 890 MHz and 920 MHz.

3. System Concept 3. This concept was viewed as a necessary extension to System Concept 1 in situations where direct communication between the grade crossing and locomotive transceivers is blocked.

With any IVSAWS implementation, BN recommended a constant 45 second advance warning time. Immediate system turn off after train departure from the crossing was highly recommended in order to minimize driver irritation and maximize driver confidence in the system. IVSAWS may also need to address system confusion factors including multi-train, multi-track crossing situations, particularly situations where different railroads own separate tracks and locomotive configurations may differ.

BN's preference for a crossing-based IVSAWS transmitter (System Concept 2) is partially motivated by economics. Railroad crossings, including instrumentation, are traditionally ordered by and paid for by government agencies. Maintenance is usually provided by railroad companies. Thus, from BN's perspective, a trackside IVSAWS is more cost effective than a locomotive-based IVSAWS.

BN was interested in other potential IVSAWS applications, particularly train control and train-to-train collision prevention prior to deployment of the ATCS. IVSAWS would be an "application of GPS as a non-vital safety overlay." Architecture requirements include an on-board GPS set, train-to-train radio data link, and non-proprietary computer. Operationally, the locomotive engineer would enter route information, including track ID, via a work order system embedded in the computer. Track ID and train position would then be periodically broadcast by IVSAWS and be received by nearby trains. If two trains on the same track violate minimum separation criteria, alarms would sound and, possibly, automatic braking would be applied.

Canadian Pacific Railroad (CP)

Place:	Montreal, Canada	
Date:	August 3 1,1993	
Railroad Representatives:	David Driediger	Specialist, Signal Systems
	Don Goulding	Manager, Signals and Communications
	Juri Kraav	Director, Signals and Communications
	Robert Nash	Engineer, Signals and Communications

CP was cautiously receptive of the IVSAWS concept. Liability for IVSAWS equipment and system reliability under "special circumstances" were cited as major concerns. Special circumstances include parallel tracks, short trains (e.g., locomotive only), and spotty deployment of IVSAWS among locomotive fleets (i.e., some locomotives have IVSAWS hardware, some don't). The "only way" to gain railroad industry acceptance of IVSAWS is to 1) "relieve [the] railroads of all liability" for system failures and 2) have the government pay for IVSAWS installations.

CP was also concerned with the possibility of drivers adopting false sense of security when their cars are equipped with IVSAWS. CP recommended that IVSAWS always generate an in-vehicle alert when drivers approach a crossing. Thus, if drivers don't receive a warning, they can detect system failures. If a train is in the vicinity of the crossing, the warning message could be changed to reflect train proximity.

Overall, CP rated System Concept 1 and System Concept 2 similarly. System Concept 3 was view as a special case of System Concept 1. CP made the following comments regarding the concepts:

System Concept 1. CP stated that, overall, this concept would be the most cost effective since there are many more grade crossings than locomotives. From a system-level viewpoint, putting hardware on the locomotive instead of at the crossing makes economic sense. From the railroads' viewpoint, this concept is not economically attractive since the companies traditionally pay for warning devices installed on trains. Today, minimal instrumentation (simple train detector with lights and bells) costs approximately $20,000 per crossing.

Any IVSAWS which could relay train position back to dispatch would be "received well" by railroad companies. CP noted that differential GPS operation would be required in Canada due to poor satellite positions at northern latitudes. IVSAWS would be "better without GPS." As an alternative, a transponder-based system was suggested in which the lead locomotive receives position updates from beacons mounted to train control signals. Locomotive wheel tick sensors would be used to derive train position between signals. It was noted that this solution would probably be more expensive and less accurate than GPS.

The use of GPS receivers to determine train length received considerable attention. At the end of a train, the GPS receiver would have to be mounted with the end-of-train

(EOT) device. However, EOTs are already crowded with electronics and integration would be difficult. Furthermore, EOTs are mounted to the knuckle of the last car and sit low with respect to the car's outline. In this position, blockage of GPS signals is inevitable. CP stated that train length is already available via other locomotive systems, therefore, geolocation devices mounted to the end of the train are not necessary.

CP thought a crossing location database would be difficult to maintain if updates within the locomotive had to be performed manually. "When ATCS is implemented (see BN write-up, above), the database option is feasible, in fact, the data should already be there (at ATCS transponder nodes)." In concept, local crossing locations would be automatically downloaded to locomotives while in transit.

System Concept 2. In some situations, IVSAWS may be installed at crossings already instrumented with light, bells, and/or gates. "Guarantee that the [crossing] transmitter works the same as [existing] crossing [instrumentation]." Coordination will eliminate driver confusion associated with conflicting "train present" declarations from different warning systems. If lights are active, IVSAWS should also be active. When the lights turn off, IVSAWS should stop generating in-vehicle alerts. This coordination can be achieved by providing an interface between the crossing-based IVSAWS transmitter and the train detection circuitry which activates existing instrumentation.

System Concept 3. The use of a "string" of radios to relay train detection status back to a crossing-based IVSAWS transmitter was not well received. CP stated that this concept would be too expensive to be practical. Instead, crossings with poor communication path geometry should be equipped with traditional track-based train detection circuits. As an alternative, CP suggested the use of a leaky cable to receive and forward a train's IVSAWS broadcast to the crossing-based warning unit.

Amtrak

Place:	Philadelphia, Pennsylvania	
Date:	September 1, 1993	
Railroad Representatives:	Lawrence Light	Director, Signals and Communications
	James Michel	Asst. Vice President, Design and Construction
	Stephen Strachan	Director, Operating Rules
	Robert Nash	Asst. Vice President, Transportation

Amtrak was very enthusiastic about the application of IVSAWS to minimize the frequency and severity of railroad grade crossing accidents. Amtrak averages one accident per day at grade crossings. It is a "serious problem." However, "crossing-to-vehicle notification will be a problem because of the frequency of illegal crossings." Drivers will ignore in-vehicle warnings and thus, even with IVSAWS, become involved in collisions with trains. Amtrak noted that the average driver will wait thirty to forty seconds before crossing a track with active warning devices at which at train can neither be seen or heard. School busses and vehicles carrying hazardous materials are a "good first choice" for vehicular deployment of IVSAWS since drivers of these vehicles are required to stop at crossings anyway. It was recommended that such priority vehicles be required to carry IVSAWS via congressional mandate.

Amtrak was concerned about "what happens" when the train-based IVSAWS fails. A redundant system was recommended. The locomotive engineer "must know when the system fails." This extends to IVSAWS architectures with and without train-based components.

Amtrak did not express a preference for any system concept. System Concept 3 was viewed as a special case of System Concept 1. The following comments were made regarding System Concept 1 and System Concept 2.

System Concept 1. Amtrak preferred the option of using a locomotive-based database to limit the area of alert coverage to the grade crossing intersection, thereby minimizing false driver alerts. Database management was not viewed as a significant problem. Without a database, it was thought that "limited access identifiers" could be used to limit alert dissemination. For example, a "no-interstate" identifier could be set within the warning message to prevent cars traveling interstates from be warned. Hughes pointed out that this would require IVSAWS to match vehicle position to the type of road being traveled (i.e., map matching) which is beyond the scope of a first-generation IVSAWS.

System Concept 2. Amtrak felt that timely deactivation of the IVSAWS warning zone (i.e., turning off the ground-based IVSAWS transmitter) once a train passes the crossing is important. It was recommended that, since length-of-train data is available, IVSAWS use its GPS to determine when the end of the train passes the grade crossing. Alternatively, a, traditional island circuit could be installed to inform IVSAWS when the train has passed.

Association of American Railroads (AAR)

Place:	Washington, D.C.	
Date:	September 2, 1993	
Railroad Representatives:	Howard Moody	Director, Automated Train Control Programs
	John Schershinger	Director, Highway-Rail Programs
	Charles Taylor	Director, Signals and Communications

The AAR was cautiously receptive of the IVSAWS concept. Three major obstacles to railroad industry acceptance were cited:

- Industry will be unwilling to accept a perceived increase in liability exposure due to IVSAWS
- Changing the industry's skeptical attitude towards the application of new technology to grade crossing systems will be difficult - expect strong opposition from the Brotherhood of Signal Railmen
- Cost - the cost per crossing must be less than traditional motorist warning systems.

The representatives ranked the system concepts in the following order:

1. System Concept 2 is "better from a liability viewpoint since records can be easily maintained." Each time a train passes a grade crossing, the system can record the train detection and motorist warning events. Logistically, the concept "is flawed" since every locomotive than runs U.S. track will have to be equipped with IVSAWS before the system can be turned on. Exceptional train movements may also be a problem unless IVSAWS is designed to accommodate them. Three particular movements were cited: following train movements, opposing train movements, and multi-track train movements. It was recommended that this concept employ a bi-modal warning system in which a strobe or flasher is mounted with the crossing-based transmitter.

2. System Concept 1 was "not favored" since drivers traveling roads without railroad crossings will be warned about approaching trains. A locomotive-based crossing location database would solve this problem but the database is "not going to happen" due to the database maintenance expense and the logistics associated with database dissemination.

3. System Concept 3 was rejected do to the amount of hardware involved. Each additional radio in the local area network will "increase cost and reduce reliability." It was recommended that traditional track-based detectors be used to trigger IVSAWS in situations in which train-to-crossing communication is unreliable.

Norfolk Southern Railroad

Place:	Alexandria, Virginia	
Date:	September 3,1993	
Railroad Representatives:	Adam Mastrangelo	Electrical Engineer, Research and Development

Adam made the following general comments regarding IVSAWS:

- IVSAWS must be a warning system which is secondary to existing warning systems. It "can not be a stand alone system."
- In order to be effective IVSAWS "needs to seize the vehicle because drivers will ignore the warning."

Three obstacles to IVSAWS deployment were cited:

- Putting any new warning system on the train will be resisted. The technically trivial train whistle is often the subject of lawsuits. Managers will strongly oppose a warning system as sophisticated as IVSAWS.
- Propagation of IVSAWS into private vehicles will be market-driven and thus gradual. Managers will oppose installing transmitters if most vehicles can't receive the IVSAWS signal.
- Applying IVSAWS to high priority vehicles first is the best way to begin IVSAWS deployment. However, legislation requiring high priority vehicles (e.g., school busses) to be IVSAWS-equipped will be difficult and slow to obtain. Without legislation, rail companies won't install IVSAWS in locomotives.

The system concepts were ranked in the following order:

1. System Concept 2. It was felt that this concept would most effectively issue warnings to drivers since the IVSAWS transmitter is crossing-based at known locations. The alert zone can be tailored to each crossing without the use of GPS.

2. System Concept 1. This concept relies on a crossing location database to limit the area of alert dissemination to the crossing locale. The database is "currently unmanageable."

System Concept 3 was viewed as an extension to System Concept 2 and was not evaluated separately.

CONCLUSIONS

- The primary barrier to railroad industry deployment of IVSAWS will be the reluctance of management to expose their companies to additional liability for train-vehicle collisions through introduction of a safety system for which they will be responsible. Moreover, unless mandated by law, IVSAWS deployment will only be possible if the railroad industry is convinced the system will reduce the size and number of court awards granted to individuals involved in train-vehicle accidents.
- As a group, the railroad industry is unimpassioned toward the application of IVSAWS to help reduce accident frequency and severity at grade crossings. On one hand, representatives interviewed at Burlington Northern and Amtrak were enthusiastic towards its application. On the other hand, Union Pacific representatives were opposed to the introduction of IVSAWS technology at grade crossings. In the middle, the Association of American Railroads, Canadian Pacific, and Norfolk Southern have a "wait and see" attitude. In order to gain wide industry acceptance, IVSAWS train detection and warning dissemination subsystems will need to demonstrate nearly flawless performance.
- The railroad industry is very concerned about IVSAWS human factors issued as they apply to drivers. IVSAWS should not increase the level of irritation induced by the presence of trains at grade crossings. IVSAWS should not confuse drivers. Thus, 1) false alerts need to be minimized (implies high resolution area-of-warning-coverage definition), 2) advance warning times should be consistent (warning function should account for speed and position of automobile and train), 3) IVSAWS should deactivate as soon as train leaves crossing, and 4) IVSAWS warnings should be consistent with warnings generated by other grade crossing warning systems, thus avoiding data conflicts.
- System Concept 2 is favored over System Concept 1. Due to the handshaking that occurs between the locomotive and crossing-based transceivers, it is believed that System Concept 2 has a higher probability of detecting system faults. The rail industry's preference for an IVSAWS with crossing-based transmitters (System Concept 2) is also motivated by economics. Railroad crossings, including instrumentation, are traditionally ordered by and paid for by government agencies. Maintenance is usually provided by railroad companies. Thus, from the railroads' perspective, minimizing the complexity of locomotive-based IVSAWS installations more cost effective.
- System Concept 3 should be abandoned. High cost and low reliability of a network radio set were consistently identified as system flaws. It is recommended that traditional track-based train detectors be used to trigger IVSAWS in situations in which train-to-crossing communication is unreliable.
- Integrating a GPS receiver with an end-of-train (EOT) device in order to automatically determine train length is not practical. Train length is available to 1VSAWS via other train systems. Furthermore, GPS and EOT architectures are not compatible.
- The railroad industry is split on the feasibility of maintaining and distributing a crossing-location database. Near-term, IVSAWS access to such a database does not appear possible. However, the emerging Automated Train Control System (ATCS) should make automated crossing-location database distribution possible, Still, the issue of responsibility for database maintenance will need to be resolved before the database can be fielded.

APPENDIX A

INTERVIEW CANDIDATE INFORMATION PACKAGE

HUGHES
GROUND SYSTEMS GROUP

August 15, 1993

Adam Mastrandelo
Norfolk Southern Corporation
407 S. Henry St.
P.O. Box 233
Alexandria, VA 22313

Dear Mr. Mastrangelo:

I would like meet with Norfolk Southern Corporation sometime between August 30th and "September 3rd (inclusive) in order to discuss the deployment practicality of three operational concepts for an electronic roadway hazard notification system which provides drivers with advance notification of trains approaching a railroad crossing. The meeting should last about three hours. If possible, it would be beneficial if representatives from your risk management, test engineering, and technology departments are in attendance.

The meeting will focus on the relative effectiveness and practicality of three In-Vehicle Safety Advisory and Warning System (IVSAWS) operational concepts. I've included drawings which depict the concepts. I would like to assess operational concept practicality in terms of Norfolk Southern Corporation's willingness to adopt a system of this type, equipment interface issues, reasonable system cost limits, and other system issues that you might identify. I would like to collect pertinent interface data (e.g., specifications, drawings) in order to assess the impact of possible IVSAWS-train interfaces on system design. Of particular interest to me is the feasibility of integrating a Global Positioning System (GPS) receiver with an end-of-train device.

Finally, I would like to discuss a possible Federal Highway Administration (FHWA) demonstration of IVSAWS focussed on the train-alert application. During the demonstration, several proximity alert systems (including IVSAWS) would be evaluated in a "live" testbed. I would like to know if Norfolk Southern Corporation has facilities available (e.g., isolated section of track with a simulated road crossing) that could be used within the testbed.

The enclosure will provide you with background information on the In-Vehicle Safety Advisory and Warning System (IVSAWS) program.

Thank you for your assistance. Please feel free to call me if you have any questions. I will phone you this week.

Sincerely,

Keith Shirkey
Communication Systems Engineer
(714) 441-9351
(7 14) 732-2977 (FAX)

Post Office Box 3310 Fullerton California 92634-3310
(714) 732-3232
TWX 910592-1246
TELEX 685-504

In-Vehicle Safety Advisory and Warning System (IVSAWS) Program Overview

Introduction

On September 5, 1990 Hughes Aircraft Company was awarded a contract by the Federal Highway Administration (FHWA) to identify candidate advisory, safety, and hazard situations for motorists, and provide functional specifications of an In-Vehicle Safety Advisory and Warning System (IVSAWS) in sufficient detail to permit gradual incorporation of these functions into automotive vehicles. The IVSAWS will use radio transmitters to communicate advisories and/or warnings to vehicles equipped with radio receivers. The warning units will provide drivers with advance notification of roadway hazards in order to reduce crash frequency and severity.

Candidate IVSAWS Applications

As part of the IVSAWS program, University of Michigan Transportation Research Institute (UMTRI) has analyzed the highway safety problem with respect to postulated IVSAWS applications. Accident data from Michigan, Wisconsin, and the federal General Estimates System were analyzed by safety and systems personnel at UMTRI, the FI-IWA, Hughes Aircraft Company, and General Motors Automotive Research. Focus was on scenarios in which driver response time is insufficient due to the dynamics of the situation, terrain features, or known infrastructure problems. Additional scenarios were considered for which statistical information was not available, but in which the application of IVSAWS was deemed to be potentially effective. The analysis yielded a set of roadway scenarios which are particularly hazardous despite traditional crash reduction treatments such as additional mechanical signing. The crash scenarios were ranked and prioritized according to crash frequency and injury severity. The results are given in Table 1.

Table 1. Rankings of Possible IVSAWS Applications.

IVSAWS Application	Crash Data Rank		Overall Rank
	Crash Frequency	Injury Severity	
Signalling emergency vehicle presence	**5**	**2 to 3**	**1**
Accident involved or disabled vehicle	**1**	**5 to 6**	**1**
Railroad crossing	**6**	**1**	**2**
Multiple compounding hazard conditions	**3**	**2 to 3**	**2**
Highway construction zones	**2**	**5 to 6**	**3**
Supplemental traffic control device	NA*	NA*	4
Crash site — police activated	NA*	NA*	4
School bus or other special vehicle	4	4	5
"Mini-zones" involving roadside work	NA*	NA*	6

* NA = statistical information not available

Accidents at railroad grade crossings are relatively infrequent yet are almost always fatal. Only one fourth of all railroad crossings are fully instrumented with lights and gates. Additionally, motorists are interested in the presence of a train at a railroad crossing rather than just the existence of a railroad crossing.

IVSAWS Functionality

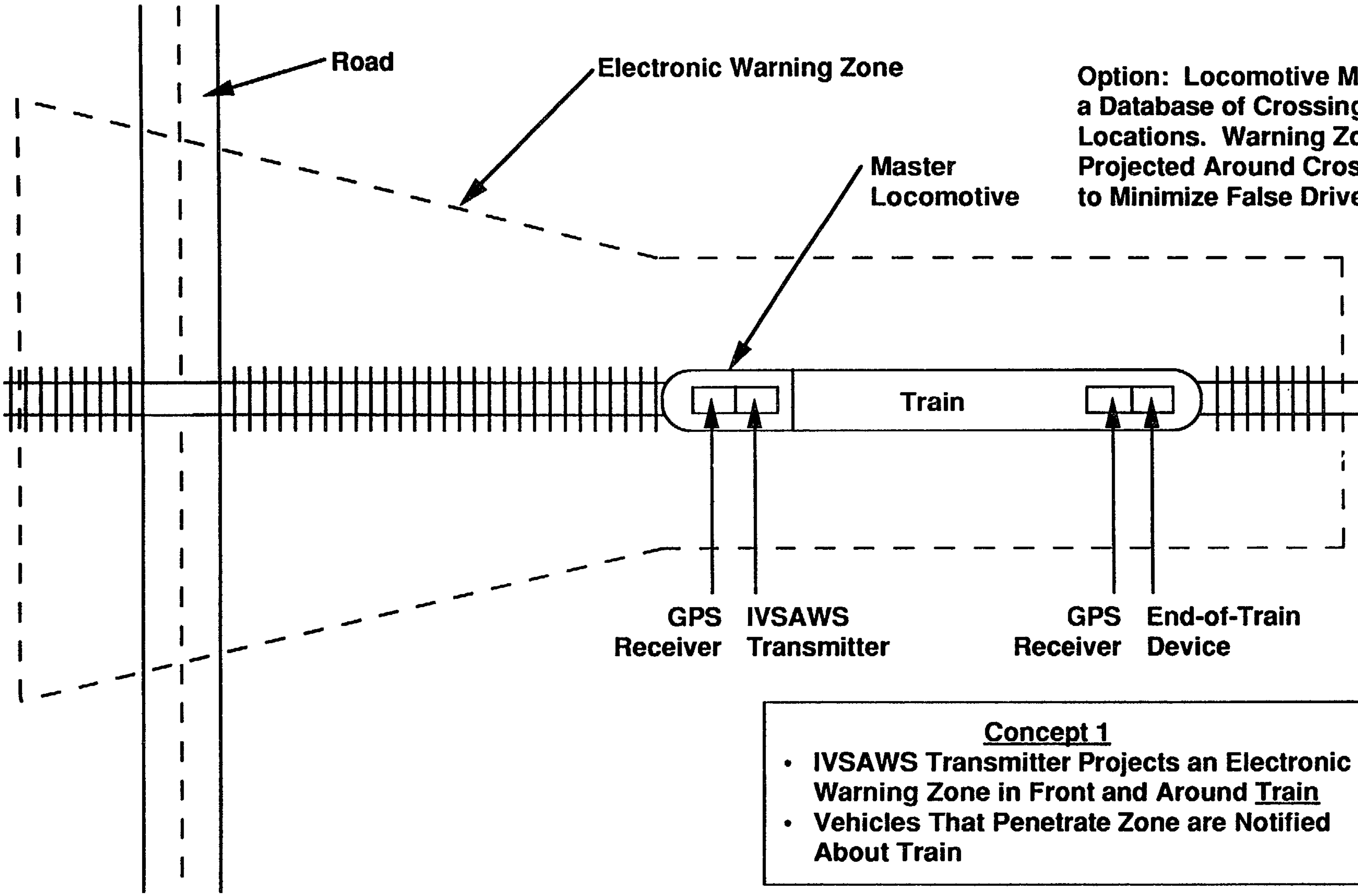
Human factors considerations are a significant consideration in the design of IVSAWS and will be the primary rationale behind the public's acceptance or rejection of IVSAWS. In addition to the basic requirement of transferring hazard warnings to vehicles, Hughes has shown that the IVSAWS-equipped vehicle should determine the range to the hazard and the closing speed between the vehicle and the hazard. The range and closing speed are used in the vehicle to compute the optimum time to warn the driver of the hazard. The rational for incorporating ranging is to minimize false driver alerts and maximize correct driver response to a valid warning by presenting the hazard alert to the driver at the optimum vehicle-to-hazard separation. The ranging function was identified as significant but not within the scope of the original study. Thus, the study was expanded to examine additional IVSAWS functions which could be supported by a more capable system. A new function was identified which allows vehicles to act as warning units in emergencies (such as when the air bag inflates). This function would reduce the chance of multi-vehicle pileups in poor visibility conditions.

IVSAWS Railroad Company Interviews

The focus of the expanded study was re-directed from the functional specification of a single "optimal" approach to an examination of several system concepts. As part of the system design effort, Hughes Aircraft Company will hold meetings with representatives from six railroad companies. Discussions will be held to assess operational concept practicality in terms of a willingness to adopt a system of this type, the amount of time and attention available for system operation, equipment interface issues, reasonable system cost limits, and other system issues identified by the companies.

No Crossing Instrumentation
(Top View)

HUGHES



Option: Locomotive Maintains a Database of Crossing Locations. Warning Zone is Projected Around Crossing <u>Only</u> to Minimize False Driver Alerts.

[FHWA L-26]

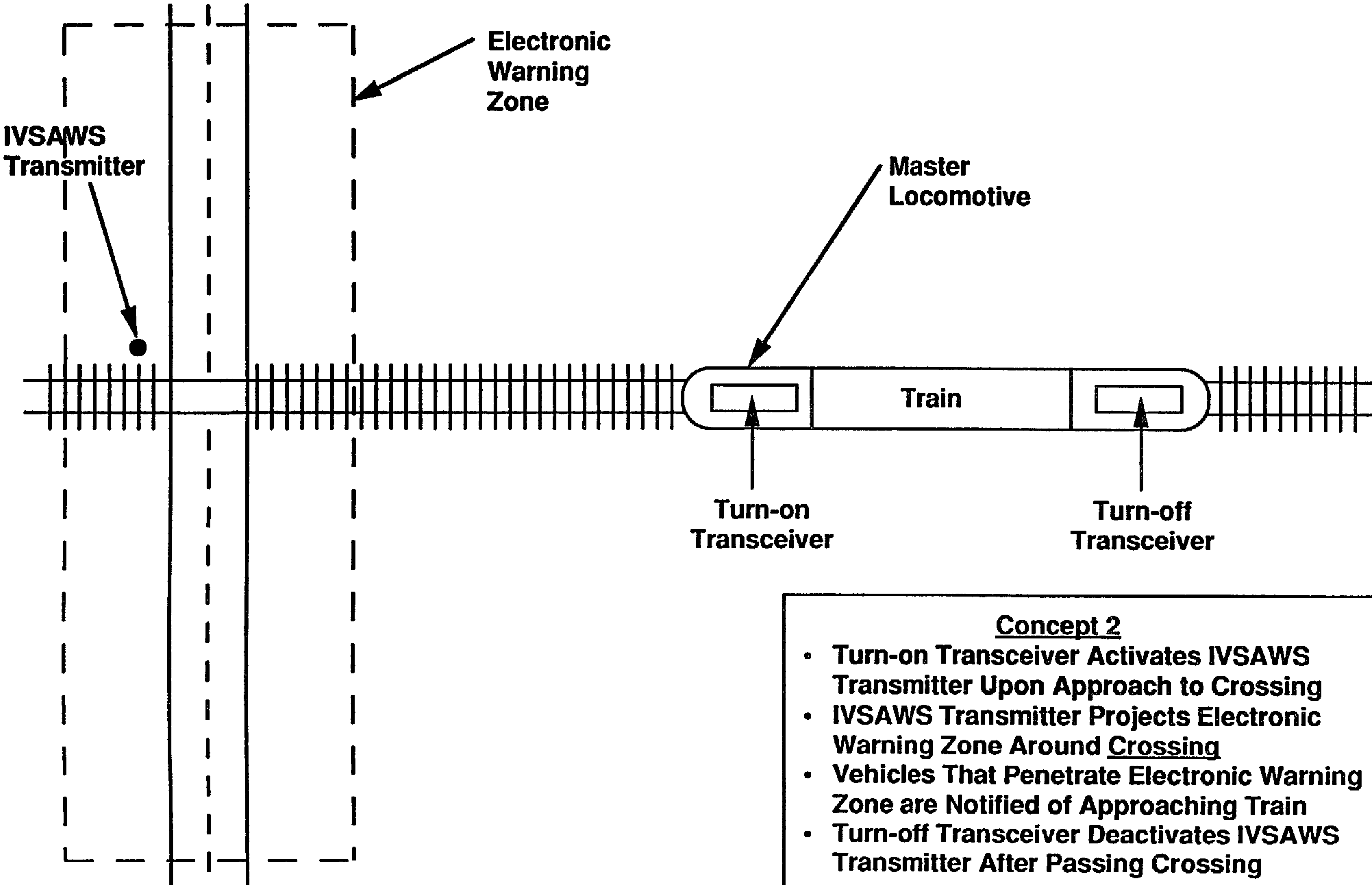
<u>Concept 1</u>

- IVSAWS Transmitter Projects an Electronic Warning Zone in Front and Around <u>Train</u>
- Vehicles That Penetrate Zone are Notified About Train

KS-2 (8/16/93)

IVSAWS with Crossing Instrumentation (Top View)

HUGHES



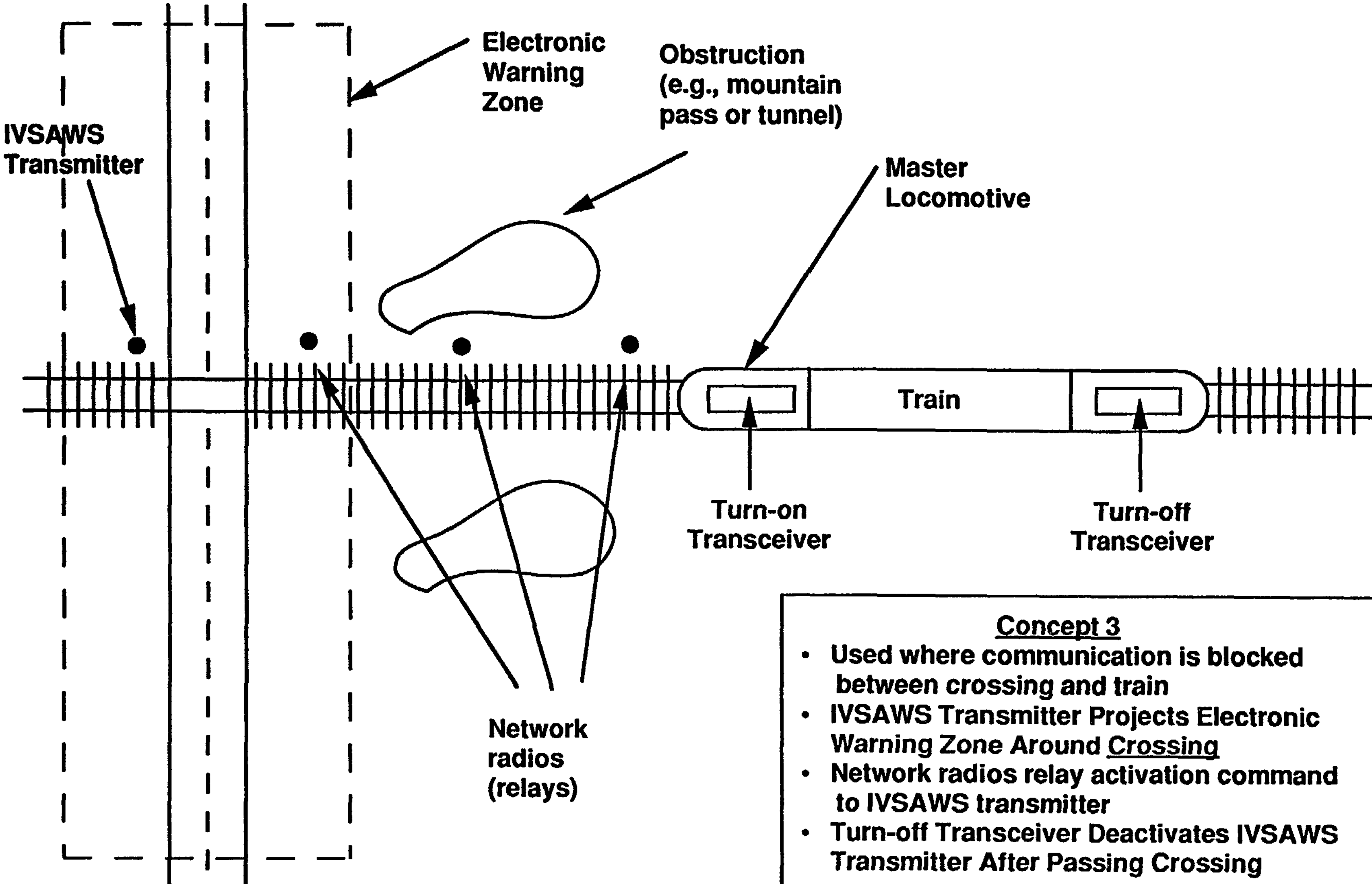
[FHWA L-27]

Concept 2

- Turn-on Transceiver Activates IVSAWS Transmitter Upon Approach to Crossing
- IVSAWS Transmitter Projects Electronic Warning Zone Around Crossing
- Vehicles That Penetrate Electronic Warning Zone are Notified of Approaching Train
- Turn-off Transceiver Deactivates IVSAWS Transmitter After Passing Crossing

KS-1 (8/16/93)

IVSAWS at Problem Crossing
(Top View)



<u>Concept 3</u>

- Used where communication is blocked between crossing and train
- IVSAWS Transmitter Projects Electronic Warning Zone Around <u>Crossing</u>
- Network radios relay activation command to IVSAWS transmitter
- Turn-off Transceiver Deactivates IVSAWS Transmitter After Passing Crossing

[FHWA L-28]

WARNING SYSTEM ALERTING DRIVERS TO PRESENSE OF TRAIN

WARNING SYSTEM TRANSMITTER PLACED ON TRAIN

HAZARD ADVISORY AND WARNING SYSTEM ARE AUTOMATICALLY ENERGIZED WHEN LOCOMOTIVE IS RUNNING (STATIONARY OR MOVING). A WARNING ZONE IS PROJECTED IN FRONT OF AND AROUND TRAIN, WARNING DRIVERS THAT A.TRAIN IS APPROACHING OR IN THEIR PATH.

WARNING SYSTEM TRANSMITTER PLACED AT INSTRUMENTED RAILROAD CROSSINGS

WARNING SYSTEM TRANSMITTERS ARE INSTALLED AT PREVIOUSLY INSTRUMENTED CROSSINGS AND “TAP” INTO INSTRUMENTATION POWER AND SWITCHING. WHEN ACTIVATED, THE WARNING SYSTEM PROJECTS A WARNING ZONE ONTO ROADS APPROACHING THE CROSSING. AS VEHICLES ENTER WARING ZONE, THEY ARE ALERTED TO THE PRESENSE OF TRAIN WHICH ACTIVATED INSTRUMENTATION.

INTERFACE ISSUES

1. IN EACH CASE, HOW WOULD THE WARNING SYSTEM ACCESS 12VDC OR OTHER POWER SUPPLY?
2. IN EACH CASE, HOW MUCH SPACE IS AVAILABLE FOR WARNING SYSTEM TRANSMITTER AND ANTENNA?
3. HOW WOULD WARNING SYSTEM “TAP” INTO LOCOMOTIVE SPEEDOMETER TO AUTOMATICALLY SENSE WHETHER VEHICLE IS MOVING OR STATIONARY?
4. DO LOCOMOTIVES PRESENTLY EMPLOY, OR ARE THERE PLANS TO EMPLOY, A GLOBAL POSITIONING SYSTEM (GPS) RECEIVER? IF SO, HOW COULD THE WARNING SYSTEM INTERFACE TO THIS DEVICE?
5. A WARNING SYSTEM “DISABLE” SWITCH MIGHT BE USEFUL. IF SO, WHERE SHOULD IT GO?
6. IN SCENARIO 2, HOW WOULD TRANSMITTER “TAP” INTO THE CIRCUIT WHICH SENSES THE PRESENSE OF A TRAIN?
7. IN SCENARIO 1, IT MIGHT BE USEFUL TO AUTOMATICALLY DISABLE TRANSMITTERS WHEN THE TRAIN ENTERS A SWITCHING YARD OR OTHER AREA IN WHICH MOTORISTS NEED NOT BE NOTIFIED. A DATABASE COULD BE MAINTAINED SUCH THAT THE WARNING SYSTEM “KNOWS” WHERE THESE AREAS ARE. THIS DATABASE MIGHT NEED PERIODIC UPDATES. DO MAINTENACE PERSONNEL CURRENTLY USE PERSONAL COMPUTERS OR OTHER DATA ENTRY

APPENDIX M:
MARKET-POTENTIAL ASSESSMENT OF IVSAWS RESEARCH AMONG THE GENERAL PUBLIC AND DEPLOYMENT PROFESSIONALS

This appendix contains the results of a market potential assessment for IVSAWS. Focus groups and surveys were used for selected persons in the general driving public and deployment community. The market assessment addressed the following objectives for the general driving public: overall driver reaction to the IVSAWS concept, features/issues/price points most likely to stimulate purchase, and situations in which the driver would find the system most useful. The market assessment addressed the following objectives for the deployment community professionals: general reaction to the IVSAWS concept, perception that the system will increase safety, deployment time and attention estimates, user interface issues, reasonable system cost limits, and other system/user issues identified by organizations.

MARKET POTENTIAL ASSESSMENT OF IVSAWS RESEARCH AMONG THE GENERAL PUBLIC AND DEPLOYMENT PROFESSIONALS

A MARKETING RESEARCH REPORT TO :

HUGHES AIRCRAFT COMPANY

GROUND SYSTEMS GROUP

SENSORS AND COMMUNICATION SYSTEM DIVISION

FULLERTON, CALIFORNIA

AUGUST,1992

[FHWA M-2]

4496 CORONET DR., ENCINO, CA 91316 (818) 508-6345 FAX (818) 703-4676

TABLE OF CONTENTS

BACKGROUND 1
PROJECT OBJECTIVES 2
RESEARCH METHODOLOGY-GENERAL DRIVING PUBLIC 3
RESEARCH METHODOLOGY-DEPLOYMENT PROFESSIONALS 4
EXECUTIVE SUMMARY-GENERAL DRIVING PUBLIC 5
EXECUTIVE SUMMARY-DEPLOYMENT PROFESSIONALS 6
CAVEAT 7
RESULTS-GENERAL PUBLIC 8
Market Potential-Total Sample 9
Market Potential-Rural/Palmdale vs. Urban/Encino 10
Profile Of The Sample 11
Overall Reaction To IVSAWS Concept 12
Fears And Concerns About IVSAWS 13
Expected Warning Distance 14
Warning Effectiveness Period 15
Sensitivity Of Drivers To False Alarms 16
Appeal Of May Day Function 17
Appeal Of Theft Detection Function 18
Miscellaneous 19
"Who Would Get IVSAWS First?" 20
"Where Would You Put IVSAWS?" 21
Favorite Outlet For Purchasing IVSAWS 22
Highest Price Willing To Pay For IVSAWS 23
IVSAWS Value In Specific Situations 24
Importance Of Warning Presentation Features 25

Conjoint Analysis-Additional Comments About Utility Weights .... .26

A Comparison Of Utility Values...
Top Five Utility Values-Total Sample 27
Top Five Utility Vahres-Rural/Palmdale vs. Urban/Encino 28
Relative Importance Of Warning Time Capabilities 29
Relative Importance Of False Alarms 30
Relative Importance Of Warning Distance Capabilities 31
Relative Importance Of Purchase Price 32
Relative Importance Of May Day Capabilities 33
Relative Importance Of System Features 34
Relative Importance Of Stolen Vehicle Locator Capabilities 35

TABLE OF CONTENTS (Continued)

Relative Importance Of Basic Alert Technology 36

Trade-Off Simulations

The Search For The Best Way To Design And Price IVSAWS 37

Market Share Estimates-Two Product Base Case Scenario 38

"What If?" Impact Of Adding A Mid-Range System 39

RESULTS-DEPLOYMENT PROFESSIONALS 40

Sample Profile 41

Initial Reaction To IVSAWS 43

Why Like/Dislike IVSAWS 44

Perceived Deployment Time 45

Reactions To Specific Option Features 46

User Interface Issues Of Concern 47

Perceived Cost Of IVSAWS Per Vehicle 48

Interest In Seeing Demonstration Of IVSAWS 49

Reasons For/Against IVSAWS Demonstration 50

Additional Questions/Concerns About IVSAWS 51

Additonal Comments About Utility Weights 52

A Comparison Of Utility Weights

Most Important Issues-Top Five Utility Values 53

Relative Importance Of Warning Time 54

Relative Importance Of Warning Distance 55

Relative Importance Of Purchase Price 56

Relative Importance Of Deployment Time 57

Relative Importance Of "Alert" Display Options 58

Relative Importance Of Stolen Vehicle Locator 59

Relative Importance Of Manufacturer 60

Relative Importance Of Self-Activated May Day Capability 61

Trade-Off Simulations

Product Definitions-Search For The Best Way To Design And Price IVSAWS .. .62

Market Share Estimates-Two Product Base Case Scenario .... .63

"What If?" Impact Of Adding A Mid-Range System 64

APPENDIX 65

BACKGROUND

> "Above all, we know that a new product has more chance of success the more it starts with the customers – their utilities, their values, their realities. The test of a good product is always what it does for the customer. Hence, strategies always need to **be market–focused, indeed, market driven."**
>
> Peter F. Drucker, Innovation and Entrepreneurship

The Traffic Alert and Emergency Warning System market is evolving as new technologies become available for mass market applications. Consumers will soon have numerous options competing for their attention.

DOT/FHWA and Hughes Aircraft Company, Ground Systems Group, Sensor and Communications Systems Division, are considering the development of an IVSAWS both as a built-in feature of new passenger vehicles and as a stand-alone aftermarket product.FHWA & Hughes commissioned this research to improve their understanding of potential customer's receptivity to the general IVSAWS concept and their purchase decision criteria.

Two target groups were identified for this research:

A. General Driving Public
B. System evaluators for professional deployment agencies (i.e., Law Enforcement, Fire, Paramedics, Road construction/repair, Railroad operations).

The specific objectives of this research project are listed on the following page.

OBJECTIVES OF THIS RESEARCH PROJECT

TASK A. GENERAL DRIVING PUBLIC”.

- DETERMINE OVERALL DRIVER REACTION TO THE IVSAWS CONCEPT
- DETERMINE FEATURES, ISSUES AND PRICE POINTS MOST LIKELY TO STIMULATE PURCHASE
- DETERMINE THOSE SITUATIONS IN WHICH THE DRIVER WOULD FIND THE SYSTEM MOST USEFUL

TASK B. DEPLOYMENT PROFESSIONALS...

- DETERMINE GENERAL REACTION TO THE IVSAWS CONCEPT
- DO THEY THINK IT WILL INCREASE SAFETY
- DEPLOYMENT TIME AND ATTENTION ESTIMATES
- USER INTERFACE ISSUES
- REASONABLE SYSTEM COST LIMITS
- OTHER SYSTEM/USER ISSUES IDENTIFIED BY ORGANIZATIONS

[FHWA M-6]

RESEARCH METHODOLOGY -- GENERAL DRIVING PUBLIC

Two focus group discussions were conducted in mid-July, 1992. One group consisted of nine residents of the Antelope Valley and was conducted July 16th, in Palmdale, CA The second group consisted of eleven residents from the San Fernando Valley and was held July l8th, in Encino CA The qualitative discussions were followed by computer interactive Conjoint Analysis (AKA, Trade-Off Analysis). These two survey techniques were used because high involvement purchases, like Traffic Hazard Warning Systems, are based not on a single factor or criterion, but several factors considered "jointly" (hence the term Conjoint). Qualitative questioning and a series of "which would you rather have?" questions forces consumers to reveal their priorities when making these complex decisions.

Computer interactive interviewing, compared to conventional one-on-one personal interviews, also eliminates respondent "editing" and interviewer bias. The respondents enter their answers at their own pace without any outside influences. An example of a Trade-Off question follows:

```
    WHICH TRAFFIC HAZARD AND EMERGENCY WARNING SYSTEM DO YOU PREFER?
  Type a number l-9 (from the scale below) to indicate your preference.

*********************************     *****************t*****************
*                               *     *                                 *
*                               *     *                                 *
*                               *     *                                 *
*                               *     *                                 *
* ALERT: Video Display w/icons AND *  * ALERT:  Video Display w/Map of  *
* Speech Synthesized System     *     * hazard & your car's locatlon    *
*                               *  OR                                   
* Has Self-Activated MAY-DAY    *     * No Self-Activated MAY-DAY Option *
* Option                        *     *                                 *
*                               *     *                                 *
*                               *     *                                 *
*                               *     *                                 *
*                               *     *                                 *
*                               *     *                                 *
*********************************     ***********************************

Strongly Prefer                  Don't                     Strongly Prefer
System On                        Care                            System On
Left    1 --- 2 ---- 3 ---- 4 ---- 5 ---- 6 ---- 7 ---- 8 ---- 9     Right
```

The software then distills each prospect's trade-off patterns into quantitative and observable ***utility weights***. These ***utility weights*** are indications of the relative "worth" customers place on the component of a purchase decision. Finally, these ***weights are*** used to model consumer's decision priorities. These data are very consistent with the qualitative feedback expressed during the focus group conversations.

Audio tapes of the focus groups, data tabulations and a database simulator have been provided under separate cover.

RESEARCH METHODOLOGY -- DEPLOYMENT PROFESSIONALS

Seventy-three computer interactive interviews were conducted with department professionals responsible for evaluating the merits of Traffic Hazard and Emergency Warning Systems and Devices. The survey sample combines Deployment Agency information from these areas:

Los Angeles Metropolitan Area

Orange County, CA

Ventura/Oxnard, CA

Santa Barbara, CA

Bakersfield/Kern County, CA

San Francisco Metropolitan Area

Reno, NV

Phoenix, AZ

The computer survey collected background profile data., responses to the IVSAWS concept and specific feature/user interface issues and Conjoint Analysis questions. Several open end questions were also included to probe attitudes and opinions.

The final sample consists of this many interviews by organization...

25 = Police/Law Enforcement

16 = Fire Departments

15 = Paramedics/Ambulance

8 = Road Construction/Repair

4 = Railroad Operations

5 = Other

Data tabulations and a database simulator have been provided under separate cover.

EXECUTIVE SUMMARY – GENERAL DRIVING PUBLIC

- THE MAJORITY OF THE GENERAL DRIVING PUBLIC IS "INTERESTED" IN THE IVSAWS CONCEPT'.
- URBAN DRIVERS ARE MORE INTERESTED THAN THEIR RURAL COUNTERPARTS.
- THE MARKET IS READY NOW. 75% OF THE GENERAL DRIVING PUBLIC WANT A SYSTEM FOR THEIR CURRENT VEHICLE.
- THE DRIVING PUBLIC LIKES THE CONCEPT FOR THREE PRIMARY REASONS.

  1. SAVING TIME/AVOIDING TIE-UPS
  2. ENHANCES SAFETY
  3. HELPS DRIVERS STAY INFORMED AND "IN-CONTROL"

- THE MAXIMUM AMOUNT MOST DRIVERS ARE WILLING TO PAY IS BETWEEN $250 AND $350. HOWEVER, MANY PEOPLE ARE WILLING TO PAY MORE TO GET EXTRA FEATURES LIKE LOCATION MAPS, MAY DAY ALERTS AND AUTOMATIC THEFT DETECTION DEVICES.
- EACH OF THESE OPTIONS ARE WORTH AN ADDITIONAL $50-$100.
- FALSE ALARMS ARE NOT AN ISSUE ON AN UNAIDED BASIS. HOWEVER, THEY EMERGE AS "VERY IMPORTANT" WHEN INCLUDED IN THE CONJOINT SURVEY.

THE CON JOINT SURVEY SHOWS...

- ADEQUATE WARNING DISTANCE (ONE AND ONE-HALF MILES), WARNING TIMES (TWO TO THREE MINUTES) AND FEW FALSE ALARMS (1 PER MONTH) ARE THE THREE SYSTEM ISSUES PEOPLE VALUE THE MOST.
- VIDEO DISPLAYS WITH MAPS OF THE HAZARD AND DRIVER'S VEHICLE LOCATION OR MAP WITH SPEECH SYNTHESIZED SYSTEM ARE THE TWO MOST DESIRED ALERT TECHNOLOGIES.
- CONJOINT SIMULATIONS FOR TWO AND THREE SYSTEM SCENARIOS INDICATE THE $450 "LOADED" VERSION IS VERY ATTRACTIVE TO MORE THAN 50% OF THE GENERAL DRIVING PUBLIC.
- THE "LOADED" SYSTEM AT $500 AND $550 WOULD GET A 48% SHARE OF PREFERENCE IN THE THREE PRODUCT SCENARIO.

[FHWA M-9]

MARKET POTENTIAL ASSESSMENT OF IVSAWS AMONG GENERAL PUBLIC & DEPLOYMENT PROFESSIONALS, AUGUST, 1992

EXECUTIVE SUMMARY – DEPLOYMENT PROFESSIONALS

- ALMOST EVERY PROFESSIONAL EVALUATOR LIKES THE IVSAWS CONCEPT. MOST, HOWEVER, SAY THEY LIKE IT "SOMEWHAT?' AS OPPOSED TO LIKE IT "A LOT."
- NO SINGLE REASON DOMINATES DEPLOYMENT PROFESSIONALS' REASONS FOR LIKING IVSAWS. BASICALLY, THEY FEEL "IT IS A GOOD IDEA"
- DEPARTMENTS/AGENCIES CURRENTLY SPEND AN AVERAGE OF $72,000 ON HAZARD/WARNING DEVICES. THIS CALCULATES TO $0.38 PER CAPITA FOR THE POPULATIONS THEY SERVE.
- QUICK AND EASY DEPLOYMENT, ONE MINUTE OR LESS, IS A FUNDAMENTAL PERCEPTION FOR IVSAWS.
- ADEQUATE WARNING TIME AND DISTANCE ARE CRITICAL FEATURES WANTED IN IVSAWS.
- THE INITIAL PERCEIVED COST PER VEHICLE AVERAGES $900. NATURALLY, A PREMIUM IS PLACED ON EQUIPMENT SELLING FOR SUBSTANTIALLY LESS.
- CONJOINT SIMULATIONS INDICATE LOADED SYSTEMS AT $600 WOULD ACHIEVE LARGER PREFERENCE SHARES THAN BASIC SYSTEMS AT $400 OR MID-RANGE SYSTEMS AT $500.

CAVEAT:

Two focus groups and a limited number of Conjoint Surveys, as used in this study, is designed to examine issues and considerations from a general perspective. Pricing and sales estimates should not be made solely from this research. No sample of twenty members of the General Driving Public or seventy-three Deployment Agencies can mirror perfectly nor predict unerringly. What this information can do is to point the way to desirable configurations of product features that will maximize IVSAWS acceptance and sustained growth.

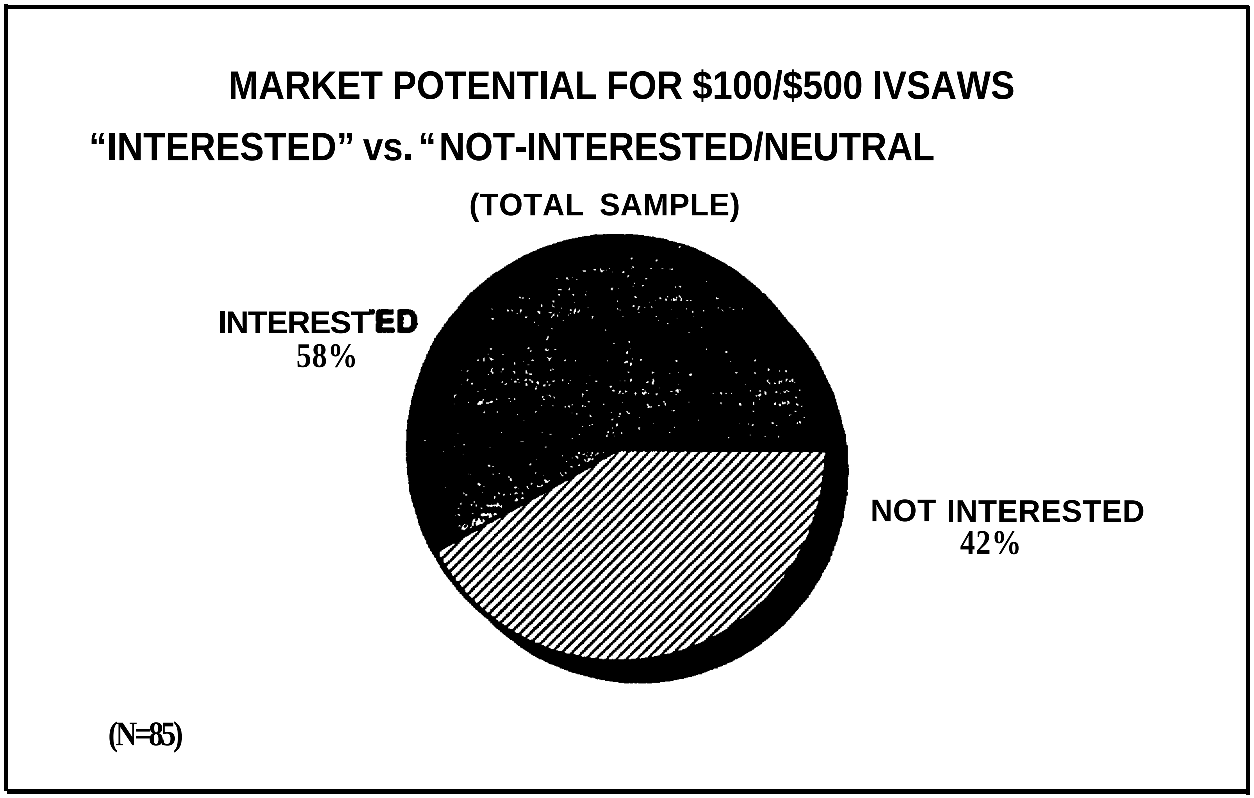
The variance of the statistics cited in this report is +/- 10% to 15% at the 90% level of confidence for "total" sample results.

RESULTS

GENERALPUBLIC

MARKET POTENTIAL-TOTAL SAMPLE

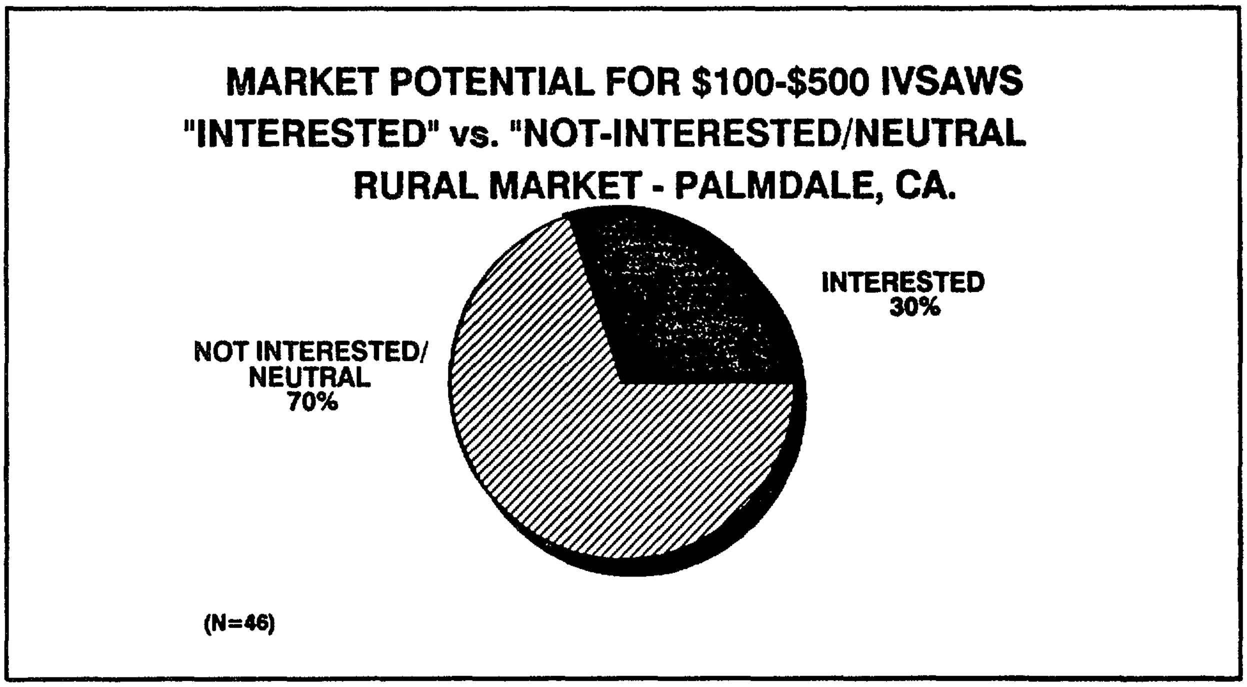
- The majority of those screened for the two focus groups are interested in the general IVSAWS concept.

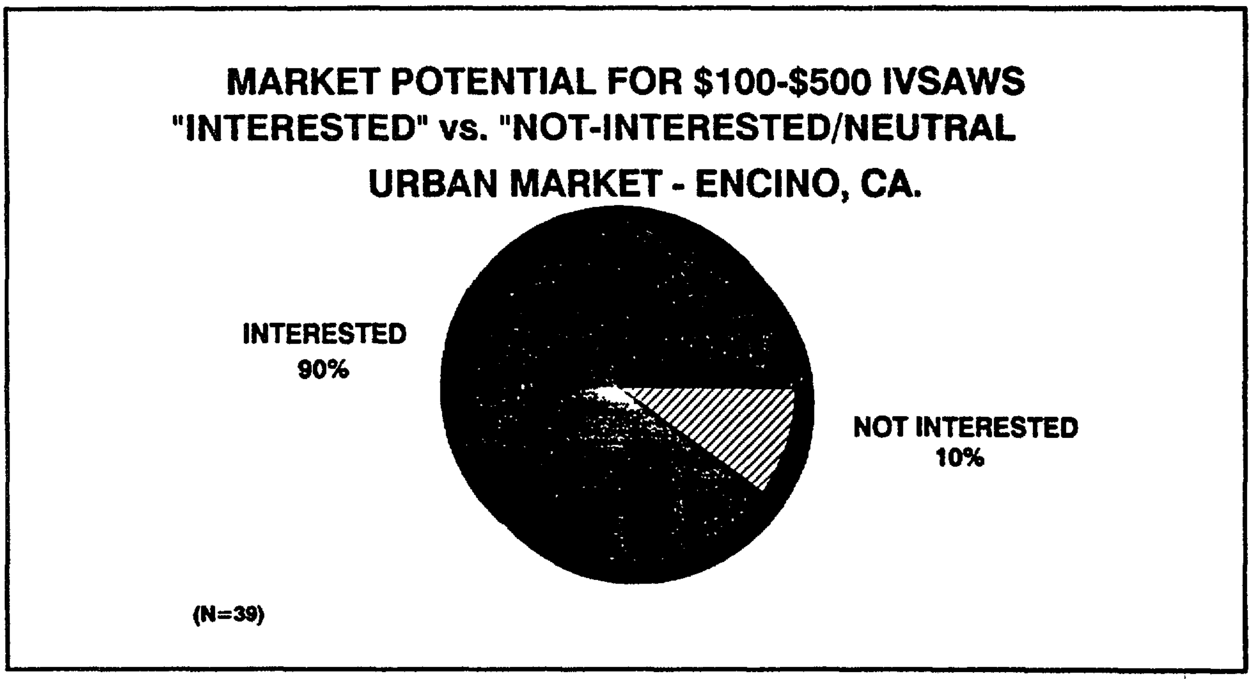


[FHWA M-13]

MARKET POTENTIAL – RURAL/PALMDALE vs. URBAN/ENCINO

- Urban drivers are more interested in the IVSAWS idea than are Rural drivers.





[FHWA M-14]

PROFILE OF THE SAMPLE

- A majority of those interviewed drive 30 + miles per day.
- Most of the interviewees drive alone on week days.
- Over half of the respondents like to "get away" to the woods, mountains, deserts &/or off-road.
- One half of the respondents listen to traffic reports on a regular basis.
- The married men in the sample are concerned with the safety of their spouses &/or family.

SAMPLE PROFILE			
GENERAL PUBLIC (N -20)			
	TOTAL	*RURAL PALMDALE*	*URBAN ENCINO*
	%	%	%
AGE:			
< 40 YEARS	50	33	64
> 40 YEARS	50	67	36
MEAN AGE	41 YEARS	45 YEARS	37 YEARS
SEX			
MALE	55	56	55
FEMALE	45	44	45
MARITAL STATUS:			
MARRIED	65	56	73
HOUSEHOLD INCOME:			
< $40K	37	56	20
$40K - $75K	42	44	40
$75K	21		40
(MEAN)	$54,000	$35,000	$72,000
(NOR)	(20)	(9)	(11)

OVERALL REACTION TO IVSAWS CONCEPT

- The Basic System was described by the focus group leader. In addition, each respondent reviewed a series of situational sketches depicting how the process works. Examples of display features were also provided.
- Almost everyone likes the general IVSAWS idea. This was true in both the Rural and Urban groups.
- SAFETY is a very important reason for liking IVSAWS. People say it will give them "peace of mind." Several others feel it will save lives.
- SAVING TIME is another primary reason the General Public likes IVSAWS. They feel more "in control" of their driving experiences.
- Many drivers like the "May Day" feature. The call-for-help benefit is equally important among Rural & Urban drivers.
- About one in four feel IVSAWS will also help Deployment Professionals do a better job.
- The mapping device, DNA appeals to a moderate but significant group of drivers,
- DIS did not elicit very much interest.
- About one-half of the drivers like IVSAWS because they want to be "knowledgeable" of traffic at all times.

FEARS AND CONCERNS ABOUT IVSAWS

Unaided responses cluster into three categories:

A. **Operations...**

Static & signal jams
Multiple accidents in the same area
False alarms
Deployment compliance
Distracting to driver

B. Maintenance...

Repairs
Heat in the vehicle
Theft protection

c. Moral...

Privacy issues

Several issues were mentioned in both focus groups. However, the lack of working demonstrations most likely contributed to drivers concerns.

[FHWA M-17]

EXPECTED WARNING DISTANCE

- After reviewing IVSAWS specs and illustrations, the General Public was asked to estimate the warning distance before encountering the traffic hazard.
- 5 % estimated two miles or less
- 45% estimated three to five miles
- 50% estimated ten miles or more

EXPECTED WARNING DISTANCE			
GENERAL PUBLIC			
	TOTAL	RURAL PALMDALE	URBAN/ ENCINO
	%	%	%
2 MILES OR LESS	5	11	--
3-5 MILES	50	33	64
10-25 MILES	35	33	36
26+ MILES	10	23	--
(NOR)	(20)	(9)	(11)

[FHWA M-18]

WARNING EFFECTIVENESS PERIOD

- The public wants time to react to traffic hazards. Rather than perceiving IVSAWS as a way to avoid accidents, most people want time to assess their alternative options.
- Urban streets allow drivers more options. Therefore, the warning alert of 2-3 minutes is appreciated.
- Because highways present the problem of possible long distances between off-ramps, a longer warning period is desired. Five minutes is deemed barely acceptable.

[FHWA M-19]

SENSITIVITY OF DRIVERS TO FALSE ALARMS

- This is not an issue that immediately concerns the public. When asked about fears and concerns, only two drivers mentioned false alarms.
- Irrelevant warning messages are not a basic concern because the public doesn't truly understand the reality and dynamics involved with deploying IVSAWS.
- However, this topic is very important to drivers when measured in the Conjoint Survey. The General Public does not expect false alarms and will not tolerate numerous occurrences.

[FHWA M-20]

APPEAL OF MAY DAY FUNCTION

- Almost everyone, Rural and Urban, wants the May Day function in their IVSAWS. This was evident from both focus group comments and the value placed on the feature during the Conjoint Survey.
- The feature is worth at least $50 to everyone . . . $100 to about half the General Public. The Conjoint Simulations support these figures.

[FHWA M-21]

APPEAL OF THEFT DETECTION FUNCTION

- Approximately three-quarters of the General Public would like the automatic theft detection feature.
- This feature is worth an extra $50-$100. The Conjoint Survey validates this extra appeal.

[FHWA M-22]

MISCELLANEOUS

- Drivers are not at all sensitive to having an IVSAWS antenna, assuming it was the size of a cellular antenna
- The General Public feels insurance companies should offer lower rates to IVSAWS owners.
- There is some concern over System repairs and upkeep. A three year parts and labor warranty is considered fair.
- System security is a concern. However, the General Public feels security will be incorporated during the installation of the System.
- Except for the additional price, everyone prefers a vehicle with IVSAWS.
- All drivers agree that IVSAWS would initially be more valuable in Urban driving conditions.

[FHWA M-23]

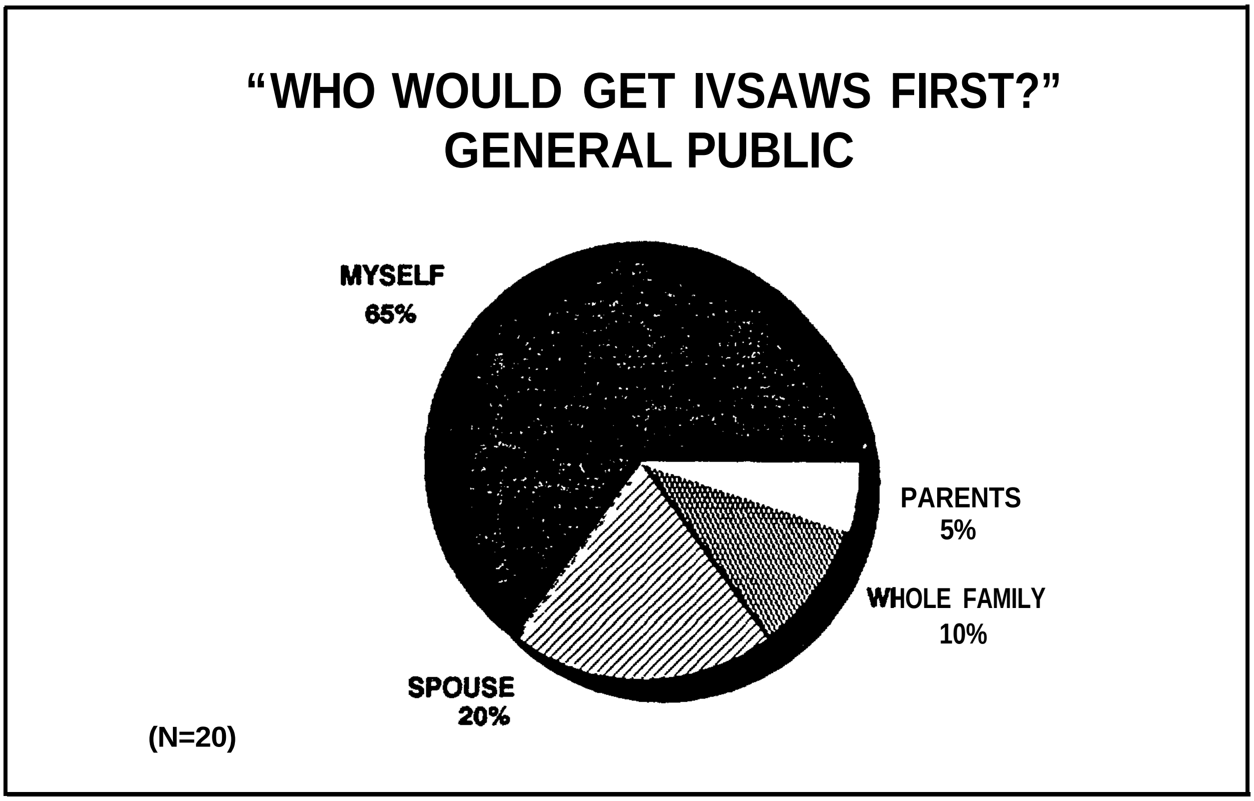
APPEAL OF THEFT DETECTION FUNCTION

- Approximately three-quarters of the General Public would like the automatic theft detection feature.
- This feature is worth an extra $50-$100. The Conjoint Survey validates this extra appeal.

[FHWA M-24]

WHO WOULD GET IVSAWS FIRST?

- Most drivers would get an IVSAWS for their own car first.
- Spouses and whole family are a distant 2nd and 3rd but reflect the value of the System to safeguard loved ones.

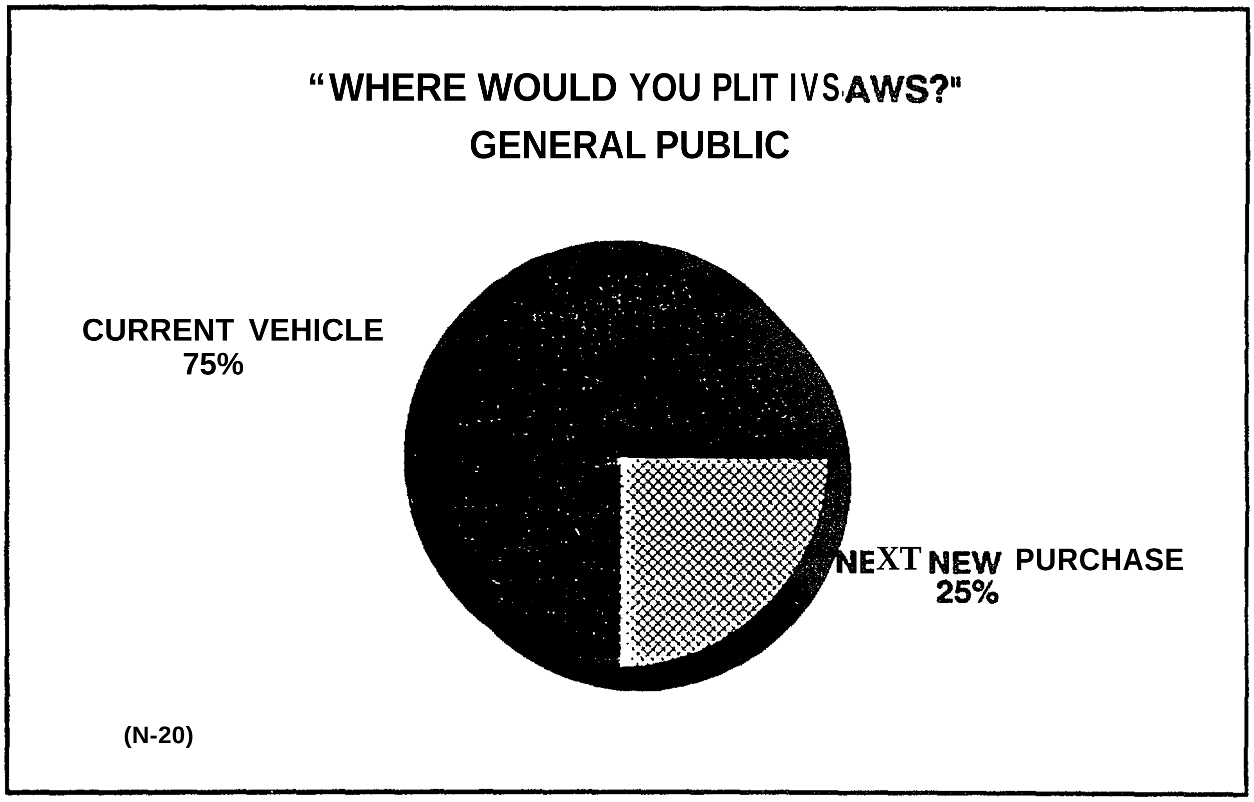


[FHWA M-25]

WHERE WOULD YOU PUT IVSAWS?

[] Three-fourths of the General Public want IVSAWS installed in their current vehicle rather that wait to purchase their next new vehicle.

[] A few people, especially Urban drivers, would like a portable System so they can switch from one vehicle to another.



[FHWA M-26]

FAVORITE OUTLET FOR PURCHASING IVSAWS

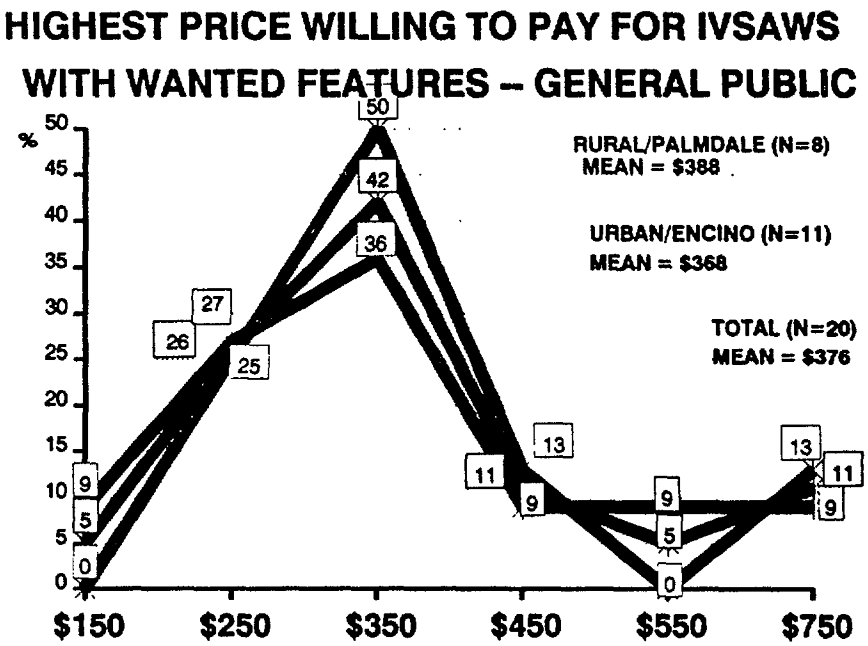
- No single outlet source dominates "favorite place" to get an IVSAWS.
- Since three out of four drivers seek IVSAWS in a current vehicle, automotivr manufacturers needs to convince the public they are "the place to go."

FAVORITE OUTLET FOR IVSAWS			
GENERAL PUBLIC			
	TOTAL	*WOULD INSTALL IN...*	
		CURRENT VEHICLE	NEW VEHICLE
	%	%	%
LOCAL INDEPENDENT AUTO ALARM SALES & SERVICE	25	33	--
INSTALLED BY AUTO DEALERSHIP IN CURRENT VEHICLE	20	27	--
LOCAL CHAIN AUTO ELECTRONICS &/OR ALARM STORES	15	20	--
AUTO DEALERSHIP BUT FACTORY INSTALLED	15	--	60
DEPARTMENT STORE AUTO SERVICES	10	13	--
AUTO DEALERSHIP INSTALL IN NEW VEHICLE	5	--	20
CELLULAR SALES/SERVICE	5	--	--
OTHER	5	--	20
(NOR)	(20)	(9)	(11)

[FHWA M-27]

HIGHEST PRICE WILLING TO PAY FOR IVSAWS

- Most drivers would spend $250-$350 for an IVSAWS.
- The demand at $750 is basically the same as $450.



[FHWA M-28]

IVSAWS VALUE IN SPECIFIC SITUATIONS

- Notification of approaching crash sites are dominate benefits to all respondents.
- Trains are more of a concern to Rural drivers than Urban motorists.
- Few drivers feel IVSAWS would not be useful in any situation.

IVSAWS VALUE IN SPECIFIC SITUATIONS			
GENERAL PUBLIC			
	TOTAL	*RURAL PALMDALE*	*URBAN/ ENCINO*
% SAYING IVSAWS WOULD BE "EXTREMELY USEFUL" SIGNALING...	%	%	%
APPROACHING CRASH SITE UNDER LOW VISIBILITY	100	100	100
ON APPROACHING CRASH SITE	91	90	91
EMERGENCY VEHICLE PRESENCE	67	70	64
TRAIN IS APPROACHING DRIVER	56	80	36
DRIVER IS TRAVELING TOO FAST	43	40	45
VEHICLE WITH AIR BAG DEPLOYED	33	30	36
APPROACHING A ROADSIDE WORK ZONE	28	30	27
APPROACHING A STOPPED SCHOOL BUS/SPECIAL VEHICLE	14	30	--
APPROACHING A RAILROAD CROSSING SUPPRESSION	9	20	--
SUPPLEMENTAL TRAFFIC INFORMATION	9	10	9
(NOR)	(20)	(9)	(11)

[FHWA M-29]

IMPORTANCE OF WARNING PRESENTATION FEATURES

- The primary warning features are the top five items under the Total column
- The differences under Rural & Urban are most likely a function of the very small sample sizes.

IMPORTANCE OF WARNING PRESENTATION FEATURES			
GENERAL PUBLIC			
WEIGHTING: 1= MOST IMPORTANT 9 =LEAST IMPORTANT 10 = NO IMPORTANCE			
	TOTAL	*RURAL PALMDALE*	*URBAN/ ENCINO*
LAYERED WARNINGS	2.9	3.6	2.2
TEXT DISPLAY OF MESSAGES	3.1	2.9	3.2
MESSAGE REPEAT FUNCTION	3.2	3.5	2.9
ICON DISPLAY	3.4	2.7	4.1
STREET MAP DISPLAY WITH LOCATIONS IDENTIFIED	3.7	4.2	3.1
SYNTHESIZED SPEECH MESSAGES	4.9	3.3	6.5
SELECTIVE DISABLE OPTION	5.1	5.2	4.9
TOTAL DISABLE OPTION	5.4	5.2	4.9
ENTERTAINMENT SYSTEM SUPPRESSION	7.7	7.9	7.5
(NOR)	(20)	(9)	(11)

[FHWA M-30]

CONJOINT ANALYSIS

SOME ADDITIONAL COMMENTS ABOUT UTILITY WEIGHTS.,

IVSAWS shoppers will make purchase decision by ***weighing*** their options. They will compare and contrast alternatives based upon the factors that are most important to them at the time.

For this survey we selected several levels of product/features and pricing alternatives to represent the scope of purchase considerations. Thirty-three decision factors were isolated (see below). Each one has a particular value ***(weight)*** for each customer...representing how much he/she wants it. The heavier the weight the more it influences the final decision, The issues that are not important receive the lightest weights.

IVSAWS ATTRUBUTE LIST-- GENERAL PUBLIC
(Version 1.2 July 9. 1992)

******* Attribute # 1 *********

1 ALERT: Video Display W/Icons

2 ALERT: Video Display W/Hap of hazard & your car's location

3 ALERT: Speech Synthesized System

4 ALERT: Video Display w/icons AND Speech Synthesized System

5 ALERT: Video Display W/Hap AND Speech Synthesized System

******** Attribute # 2 *********

/+

1 Warning Distance: 1/4 mile

2 Warning Distance: 1/2 mile

3 Warning Distance: 3/4 mile

4 Warning Distance: 1 Mile

5 Warning Distance: 11/2 Miles

******* Attribute # 3 *******

/+

1 No Self-Activated MAY-DAY Option

2 Has Self-Activated MAY-DAY

******* Attribute # 4 ******

1 Has Automatic Theft Detection & Location Reporting to Police

2 No Stolen Vehicle Detection or Reporting Capabilities

********** Attribute # 5**********

/-

1 Purchase Price: $150

2 Purchase Price: $250

3 Purchase Price: $350

4 Purchase Price: $450

5 Purchase Price: $550

********** Attribute # 6 **********

1 Features: Basic System Only

2 Features: Entertainment System Suppression

3 Features: System ON/OFF switch on steering wheel

4 Features: Supports DNA and DIS (see illustrations)

5 Features: Distance to hazard/ problem (sound or picture)

******** Attribute # 7 *********

/-

1 False Alarms: 1 Per Month

2 False Alarms: 1 Per Week

3 False Alarms: 1 Per Day

4 False Alarms: Every 2 Hours

********* Attribute # 8 ***********

/+

1 Warning Time: l0-20 seconds before hazard

2 Warning Time: 20-40 seconds before hazard

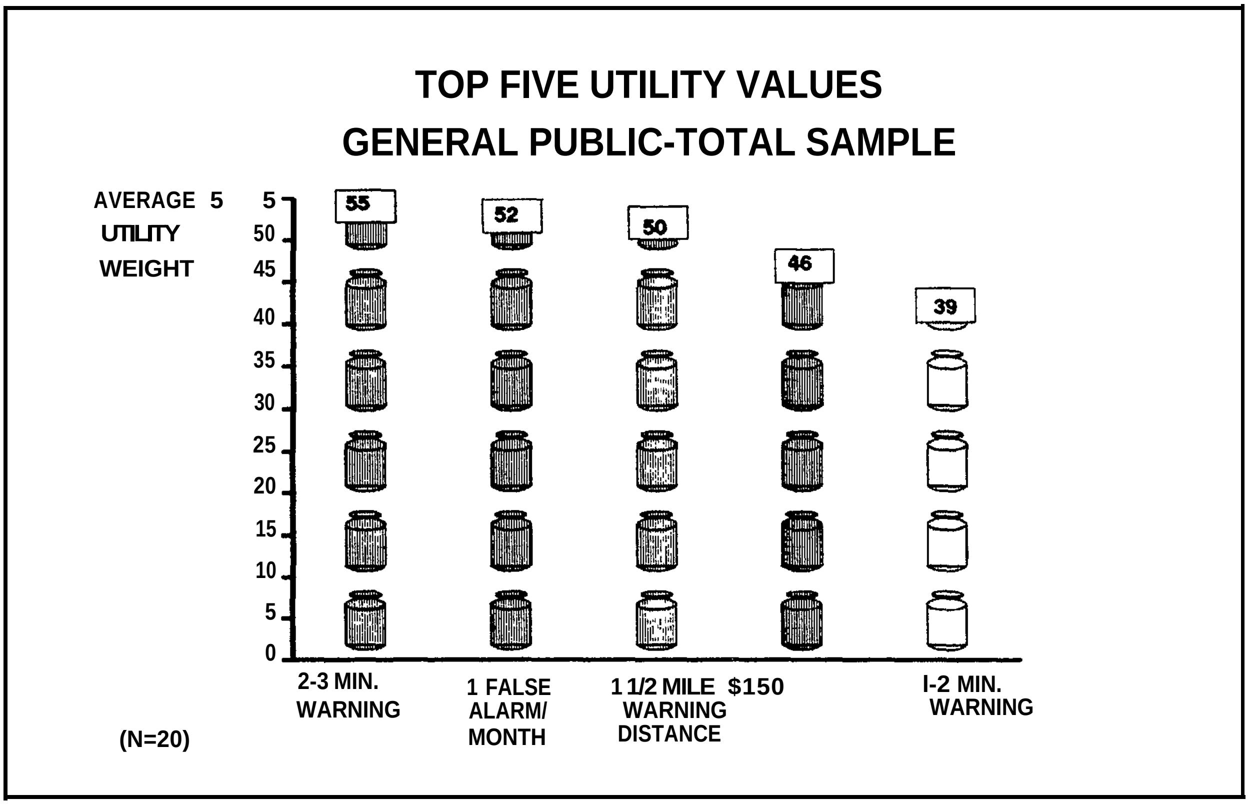
3 Warning Time: 40-60 seconds before hazard

4 Warning Time: l-2 minutes before Hazard

5 WarningTime 2-3 minutes (before Hazard)

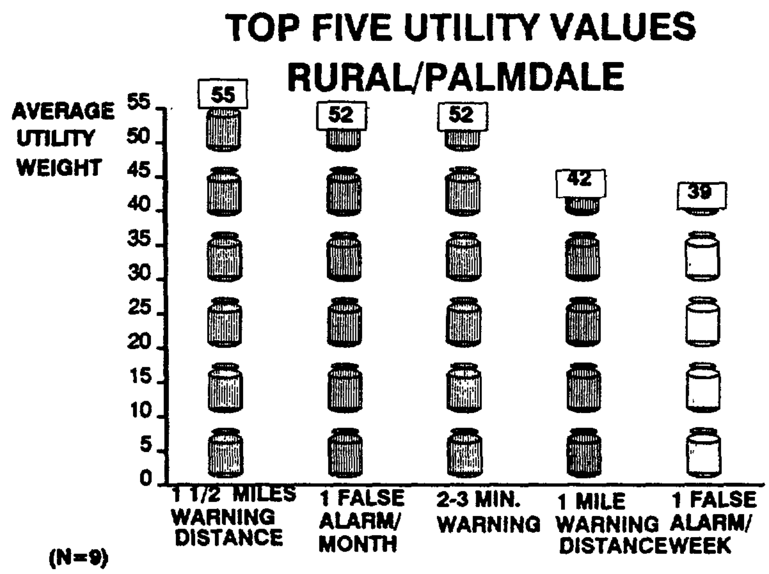
TOP FIVE UTILITY VALUES – TOTAL SAMPLE

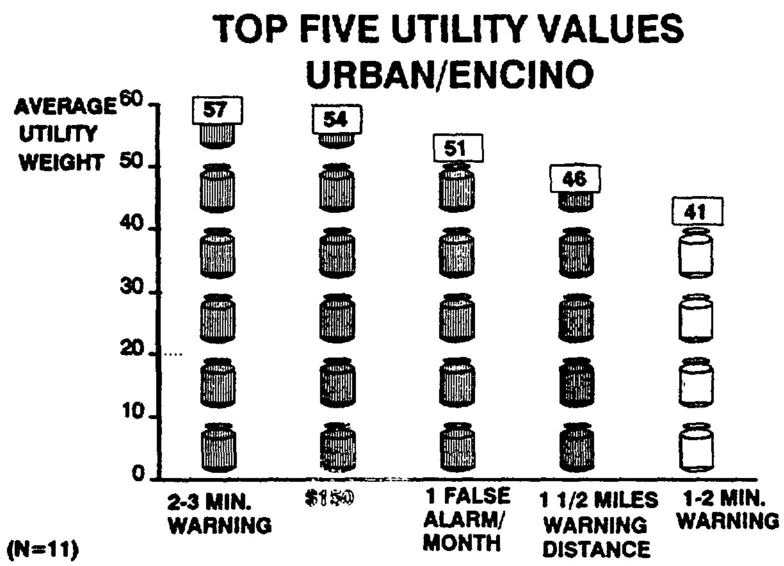
- Warning Time and Distance are three of the most important variables of IVSAWS.
- Concern for low False Alarm rates is also a critical issue. This concern, however, was not voiced during the focus group conversations.



TOP FIVE UTILITY VALUES – RURAL/PALMDALE - URBAN/ENCINO

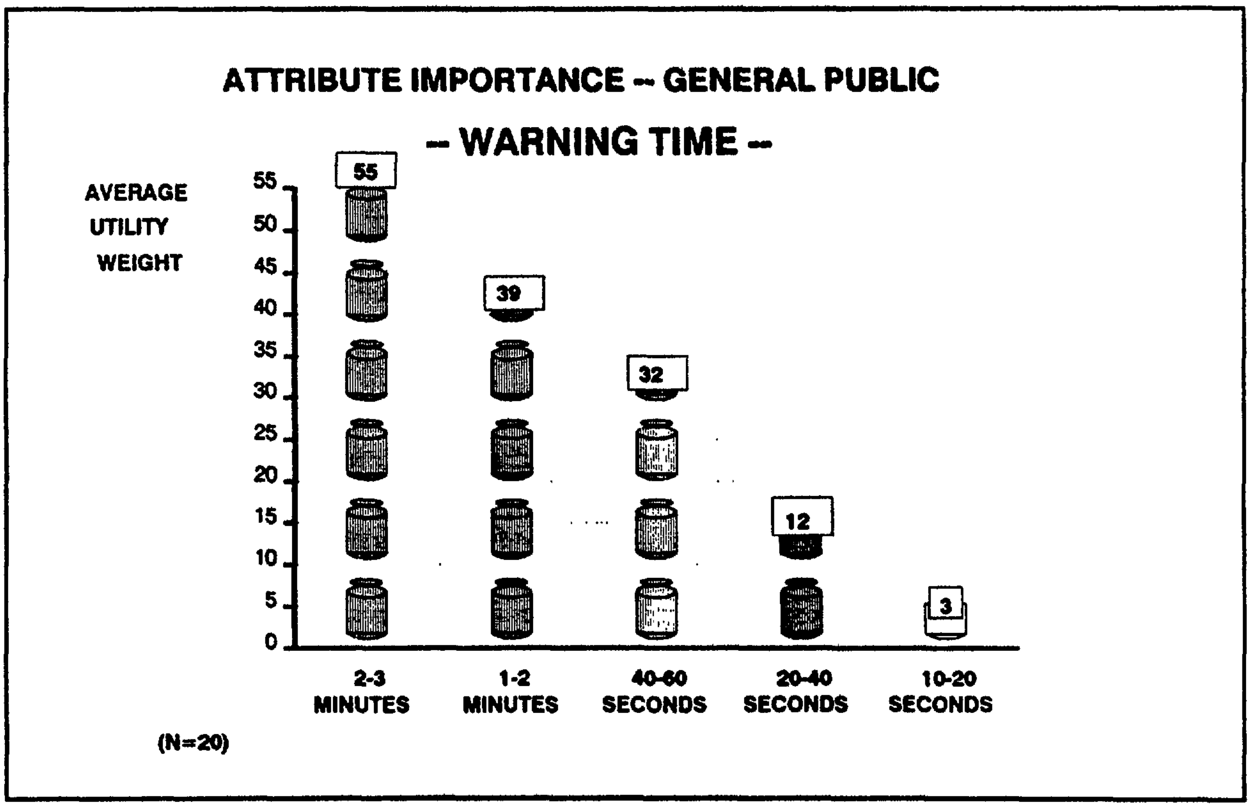
- Rural and Urban drivers are all concerned about False Alarms.
- Warning Distance and False Alarms concern Rural drivers more than the Urban drivers.





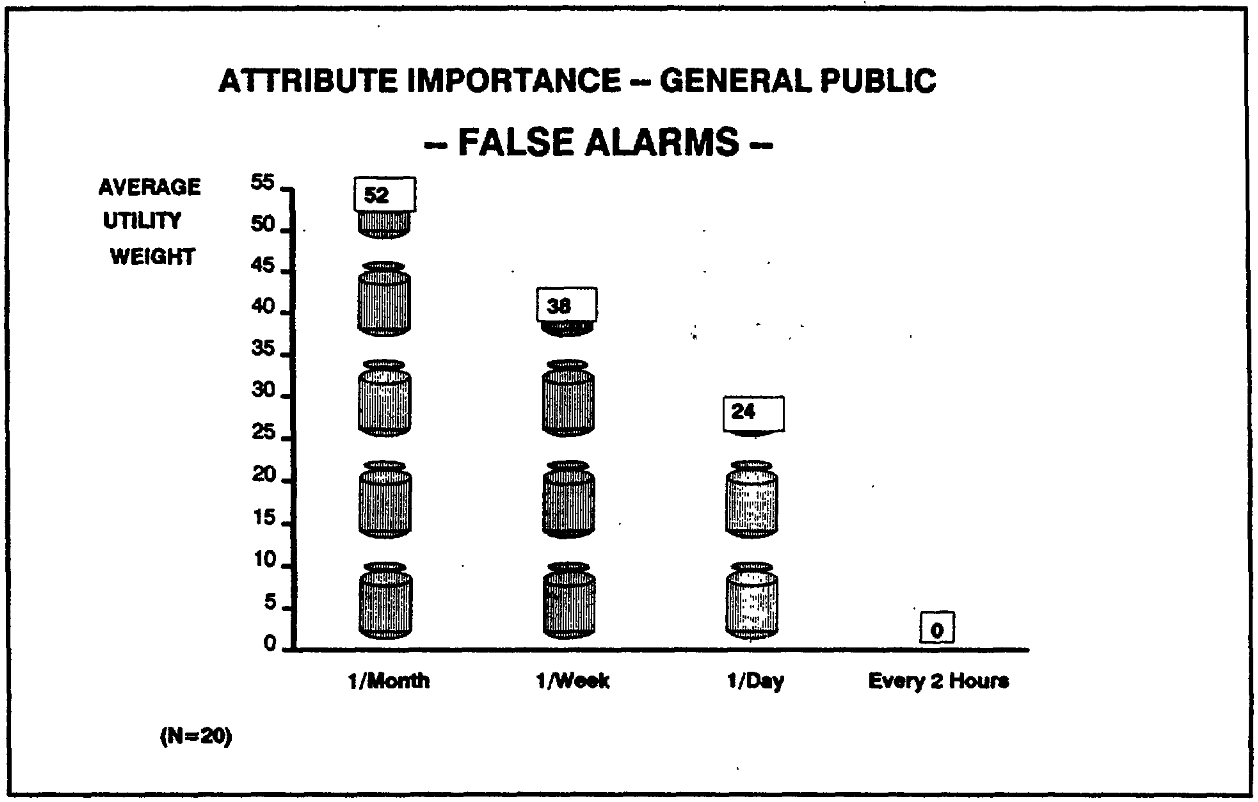
RELATIVE IMPORTANCE OF WARNING TIME CAPABILITIES

- Warning Time is a critical issue to drivers who like the basic concept of IVSAWS. The sooner they can be alerted, the more they value that time.



[FHWA M-34]

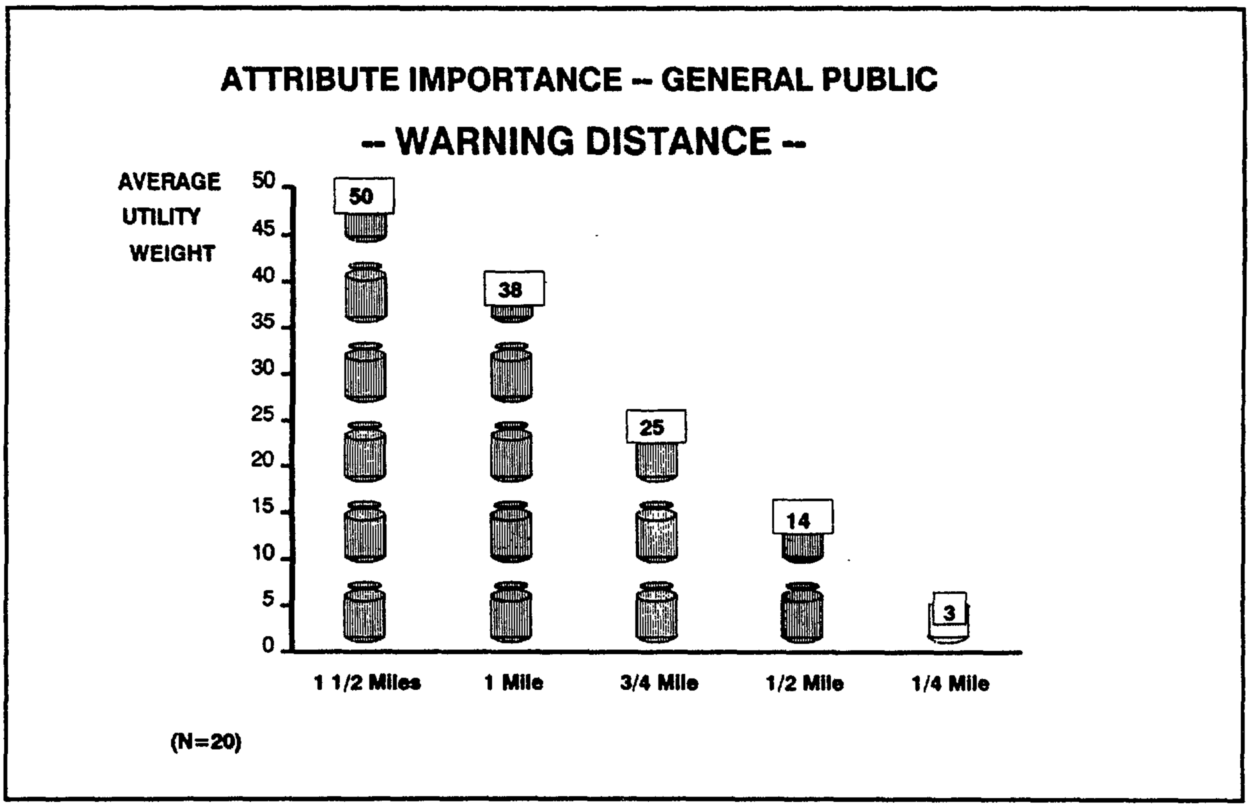
- While hardly mentioned in either focus group, this issue emerged as a very important topic in the Conjoint Survey.
- The high utility weights mean the General Public does not expect, nor will they tolerate, many false alarms.



RELATIVE IMPORTANCE OF WARNING DISTANCE CAPABILITIES

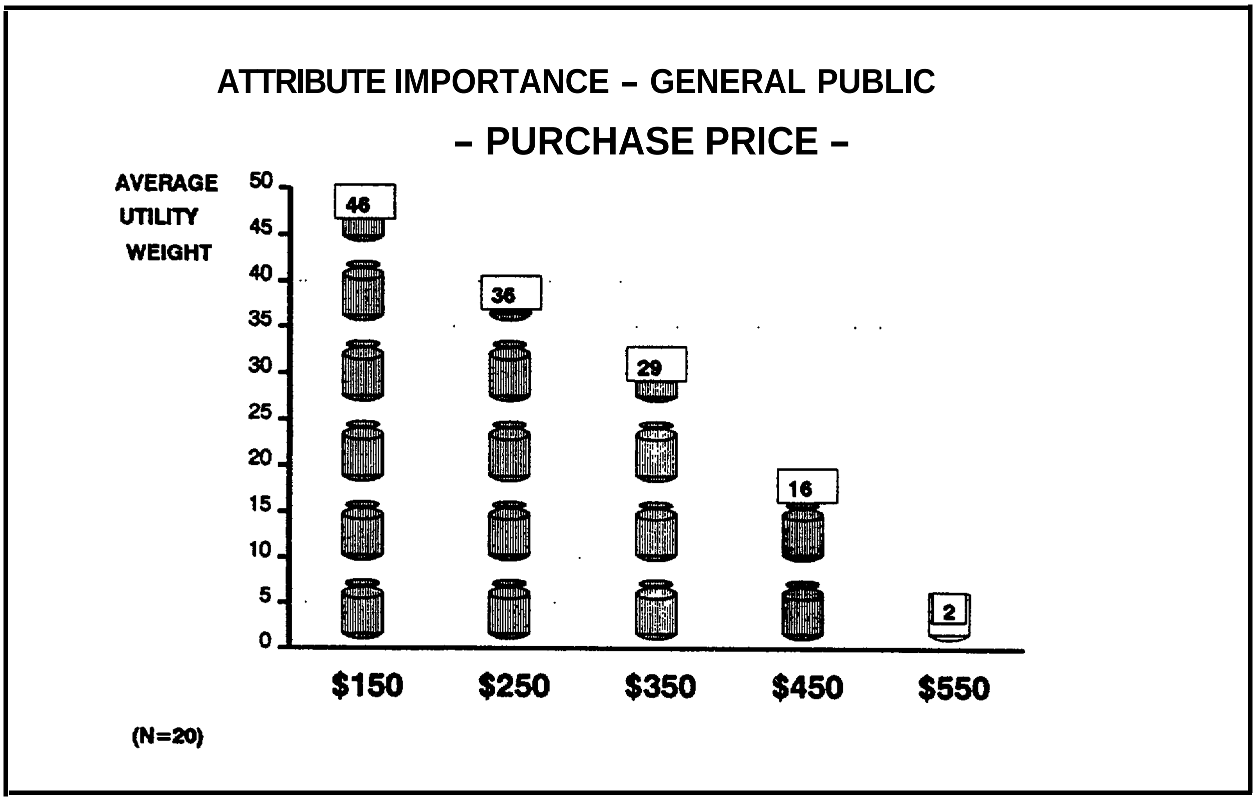
- The General Public places a lot of value in early alert. Two reasons emerged from the focus groups to support this data...

  1. Drivers like to know what is ahead.
  2. Drivers want time to make alternative choices.



RELATIVE IMPORTANCE OF PURCHASE PRICE

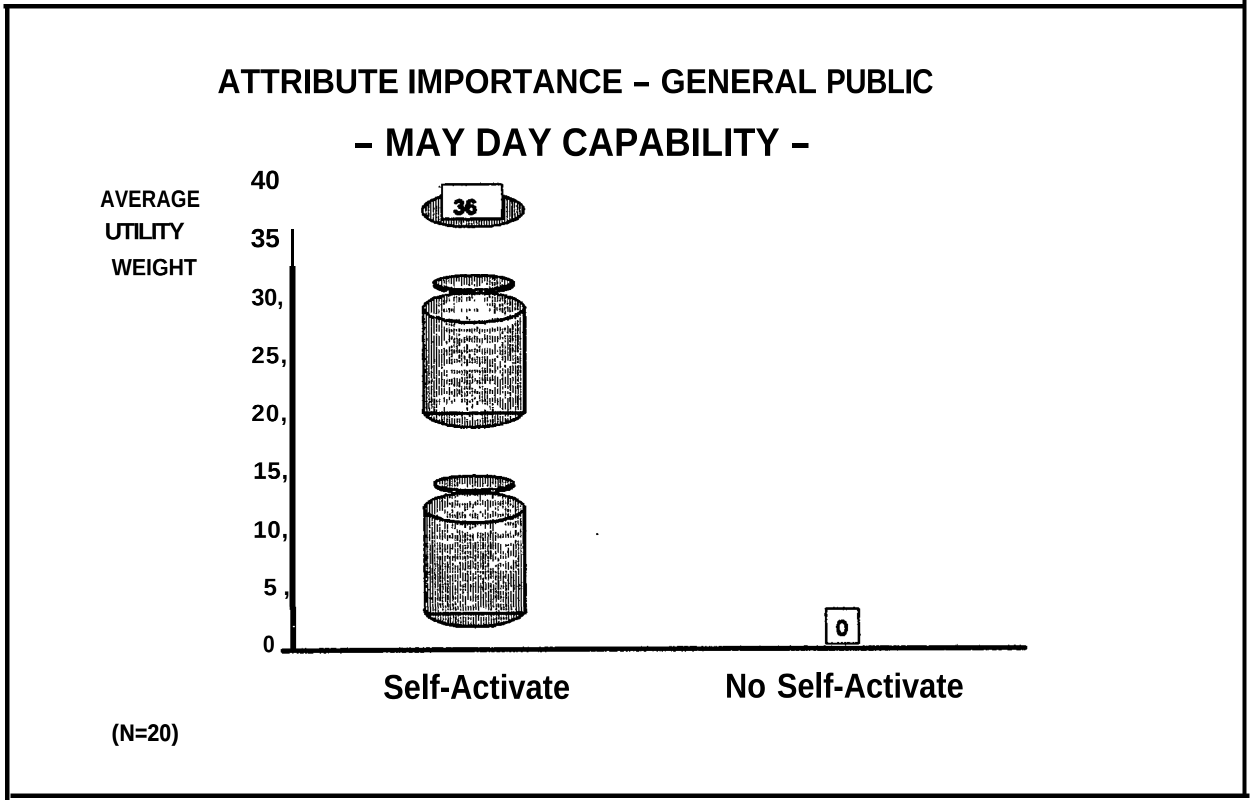
- The overall pattern of utility weights is typical for automotive Systems.
- Price is not the most important attribute. Warning Time, Warning Distance and False Alarms are of greater concern to the General Public.



[FHWA M-37]

RELATIVE IMPORTANCE OF MAY DAY CAPABILITIES

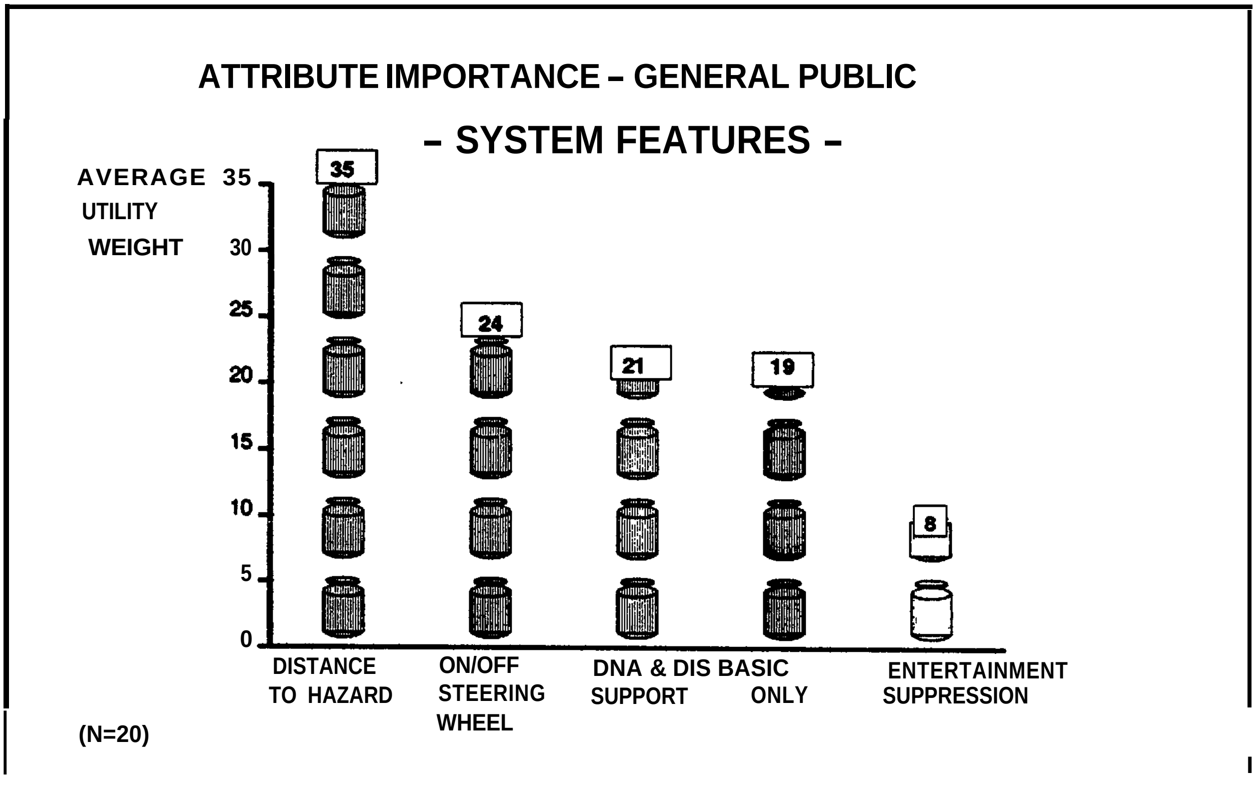
- While not a "top-five" issue, married, forty years and older and high income people like this option.
- Based upon supplementary simulations and focus groups comments, people will pay $50-$100 extra to get this feature.



[FHWA M-38]

RELATIVE IMPORTANCE OF SYSTEM FEATURES

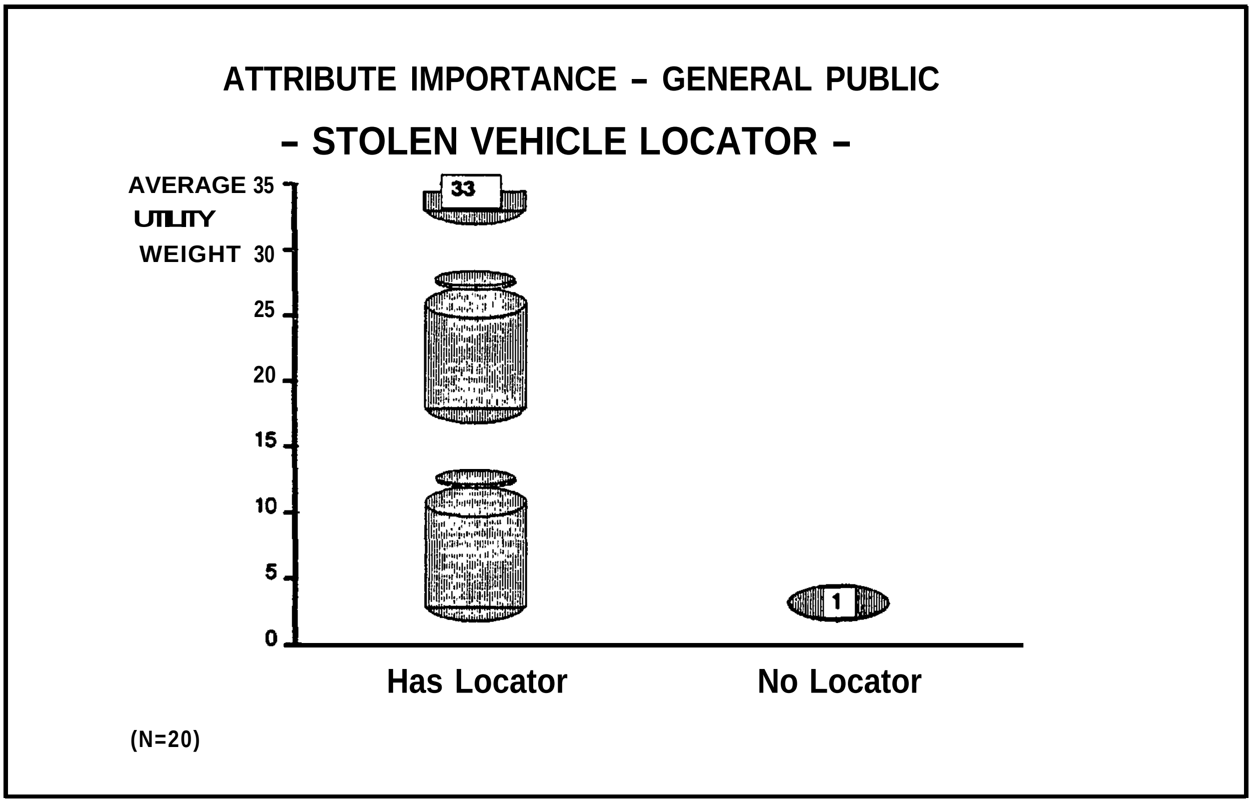
- A "Distance to Hazard" alert is the most valued feature tested in this survey.
- Entertainment Suppression is clearly the least important of these five System features.



[FHWA M-39]

RELATIVE IMPORTANCE OF STOLEN VEHICLE LOCATOR CAPABILITIES

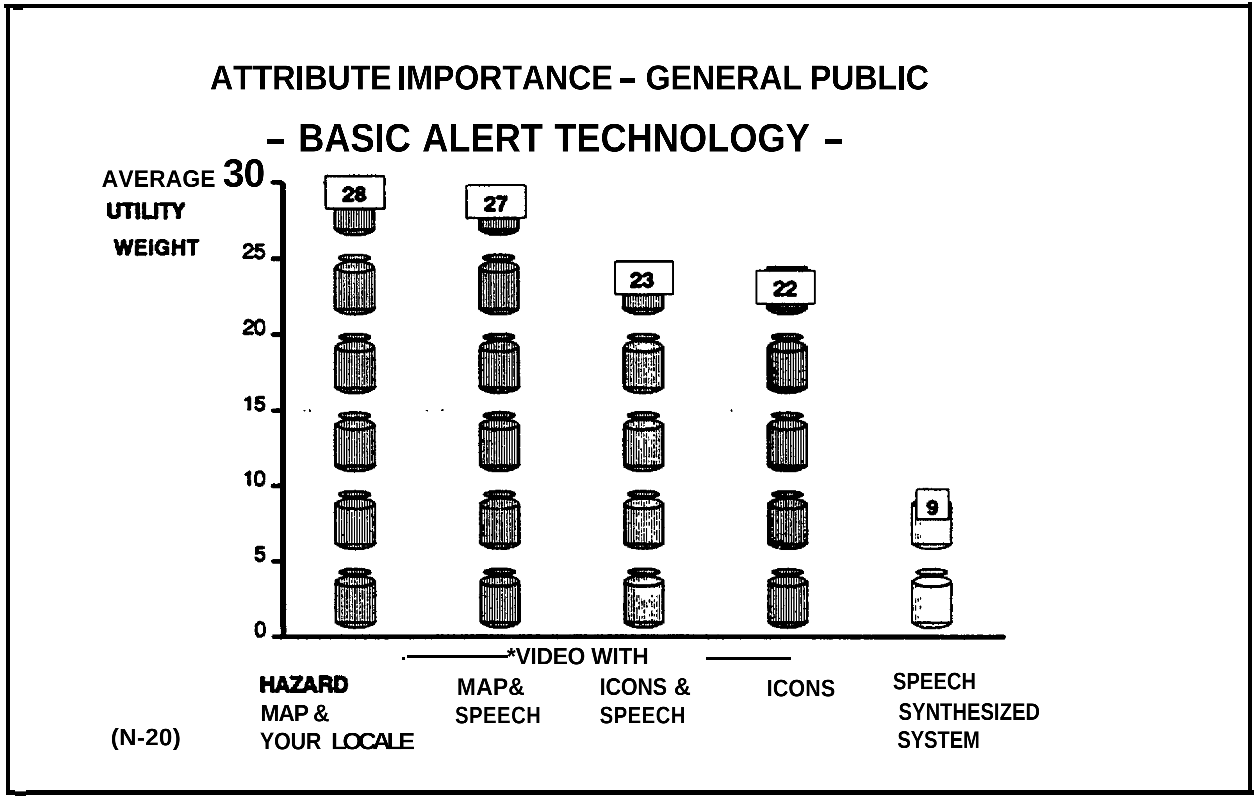
- This is another item that falls into the "middle range" of value.
- Older respondents (forty years +) like this feature the most.



[FHWA M-40]

RELATIVE IMPORTANCE OF BASIC ALERT TECHNOLOGY

- Dual alert modes with location maps are valued the most by the General Public.
- Video alert with icons and synthesized speech are two and one-half more appealing than synthesized speech alone.



[FHWA M-41]

TRADE-OFF SIMULATIONS - THE SEARCH FOR THE BEST WAY TO DESIGN AND PRICE IVSAWS

Once a customer's *utility weights* are established, it is possible to see which combination of features has the highest overall value. We refer to this process as simulating alternative scenarios. In essence, a simulation produces a "pie chart" where each product's relative appeal is represented by the size of the "slice."

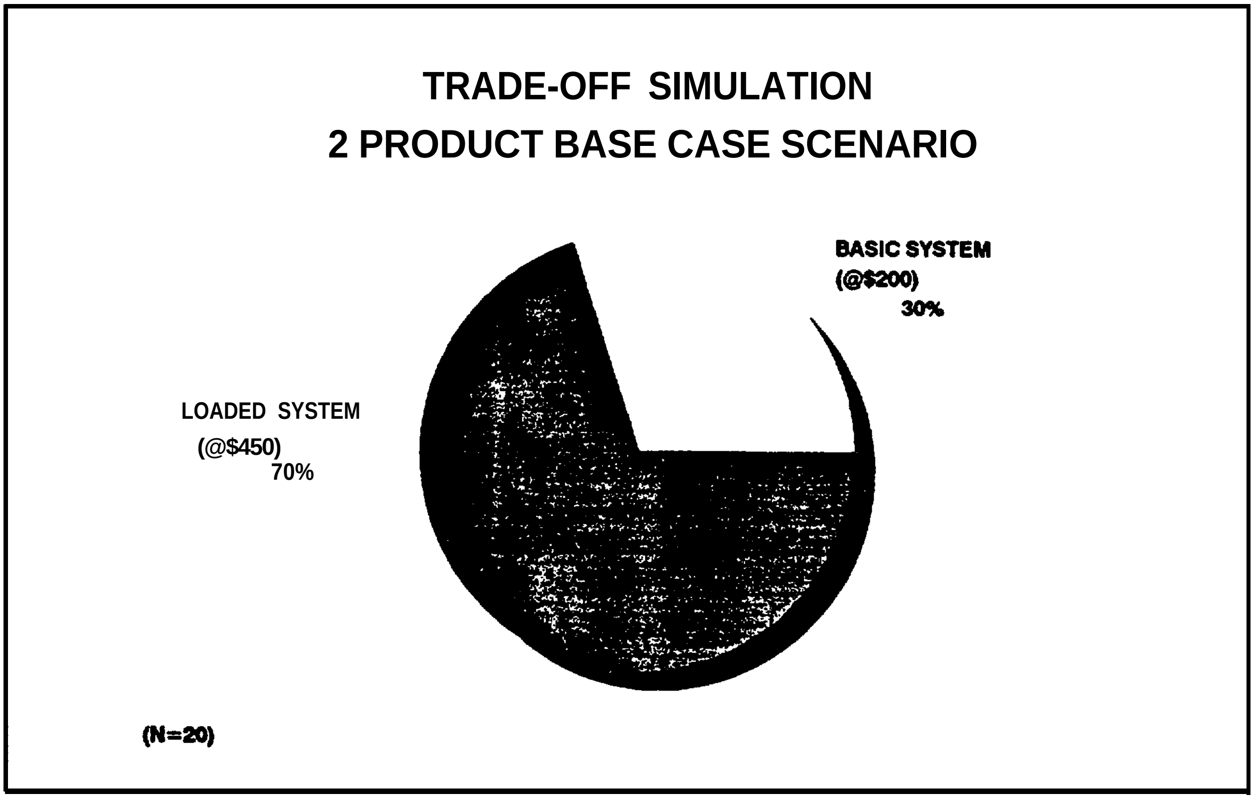
We start this process by establishing a BASE CASE...a basic set of product definitions. Two configurations, Basic and Loaded, were designated to represent a BASE CASE environment for IVSAWS. A Mid-Range System will be introduced later with the definitions shown below.

PRODUCT DEFINITIONS			
GENERAL PUBLIC			
	BASIC SYSTEM	*LOADED SYSTEM*	*MID-RANGE SYSTEM*
ATTRIBUTES:			
ALERT	VIDEO WITH ICONS	VIDEO WITH MAP & VOICE	VIDEO WITH ICONS & VOICE
WARNING DISTANCE	1 MILE	1 1/2 MILES	1 1/4 MILES
MAY DAY	NONE	YES	YES
THEFT DETECTION	NONE	YES	NO
PRICE	$200	$450	$350
FEATURES	BASIC SYSTEM	DNA & DIS	DISTANCE TO HAZARD
FALSE ALARMS	1 PER WEEK	1 PER MONTH	1 PER 2 WEEKS
WARNING TIME	1-2 MINUTES	2-3 MINUTES	2 MINUTES

[FHWA M-42]

MARKET SHARE ESTIMATES - TWO PRODUCT BASE CASE SCENARIO

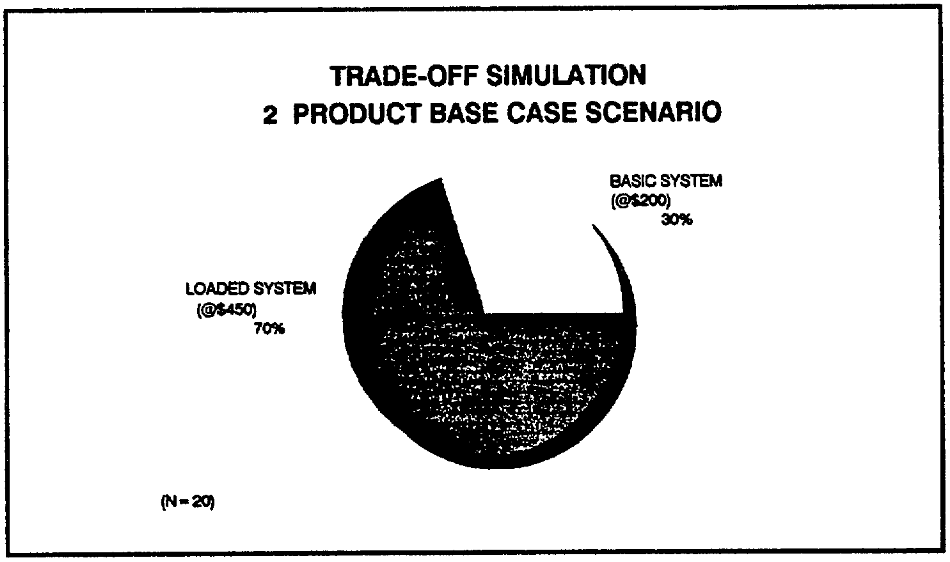
- A "Loaded" System is the overwhelming choice of customer prospects.

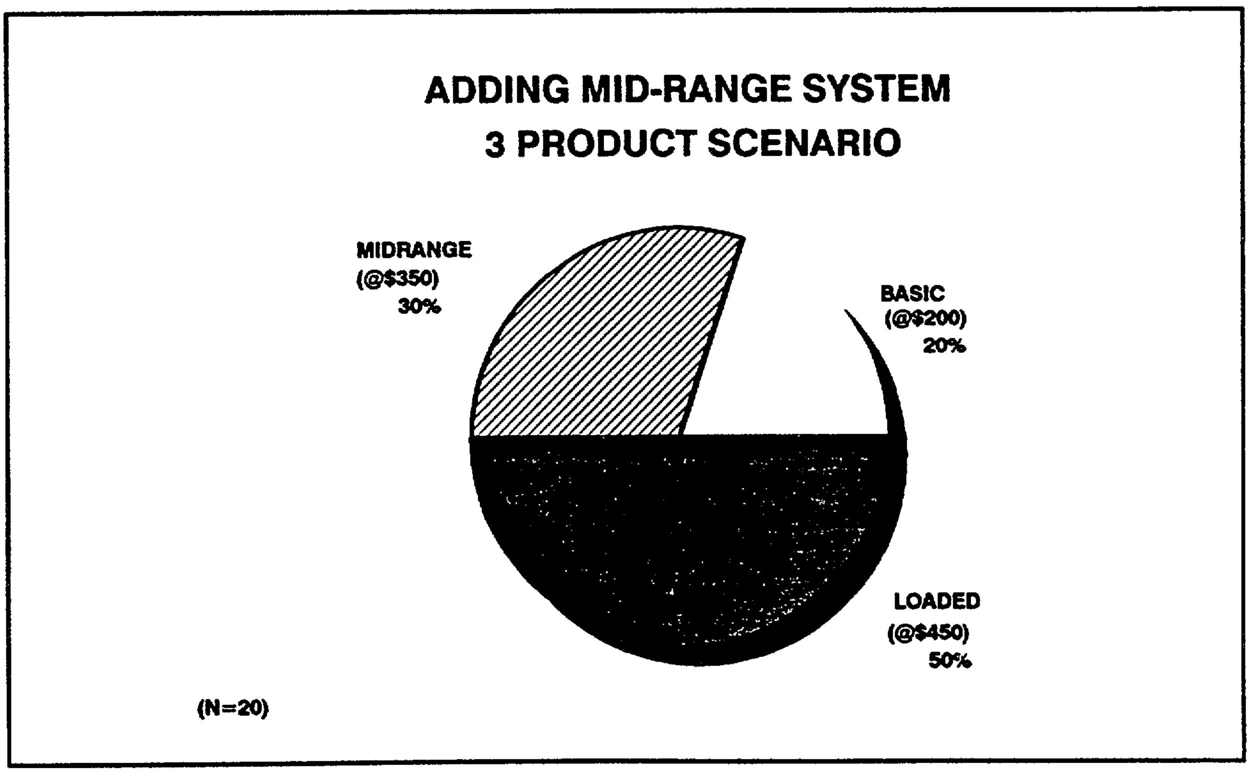


[FHWA M-43]

"WHAT IF?" IMPACT OF ADDING A MID-RANGE SYSTEM

- The Mid-Range System has a 30% "Share of Preference" when compared to a Basic and Loaded System.
- The $450 Loaded System garners a "share" of 50%. Additional calculations reveal that at $550 this System maintains its appeal (48%).





RESULTS

DEPLOYMENT PROFESSIONALS

[FHWA M-45]

SAMPLE PROFILE

- The average population served by the Deployment Agencies in thii survey is 191,000.
- The typical respondent has nine years experience evaluating Traffic Hazard and Emergency Warning Systems.
- On average one hundred sixty-six field vehicles are used by the participating Deployment Professionals.

SAMPLE PROFILE						
DEPLOYMENT PROFESSIONALS						
	TOTAL	*POLICE*	*FIRE*	*PARAMEDICS AMBULANCE*	*ROAD WORK*	*RAILROADS*
	90	*%*	*%*	*%*	*%*	*90*
POPULATION SERVED						
< 250,000	**52**	**64**	**69**	**20**	**38**	**50**
250,000-2,499,999	**27**	**20**	**13**	**53**	**25**	**25**
2,500,000 +	**21**	**16**	**18**	**27**	**37**	**25**
MEAN POPULATION	(191K)	(156K)	(15.X)	(241 K)	(310K)	(198K)
II YEARS REVIEWING/EVALUATING TRAFFIC HAZARD SYSTEMS						
< 6 YEARS	**34**	**40**	**44**	**27**	**25**	**50**
> 6 YEARS	**66**	**60**	**56**	**73**	**75**	**50**
MEAN # OF YEARS	**(9.0)**	**(8.2)**	**(7.3)**	**(10.5)**	**(11.3)**	(8.8)
# OF FIELD VEHICLES						
< 21	**33**	**16**	**50**	**33**	**25**	**50**
21 - 100	40	**48**	**19**	**53**	**38**	**25**
101+	**27**	**36**	**31**	**14**	**37**	**25**
MEAN # OF VEHICLES	**(166)**	**(229)**	**(157)**	**(101)**	**(188)**	**(188)**
(NOR)	**(73)**	**(25)**	**(16)**	**(15)**	**(8)**	**(4)**

SAMPLE PROFILE (Continued)

- Over two hundred hazard/emergency situations are encountered every week. Paramedics and Ambulances have the highest incidence rate.

[] Only $72,000 ($ .38 per capita) is budgeted for Warning Devices. On average police and Law Enforcement Agencies spend the most, $82,000 ($ .53 per capita).

SAMPLE PROFILE						
DEPLOYMENT PROFESSIONALS						
	TOTAL	*POLICE*	*FIRE*	*PARAMEDICS/ AMBULANCE*	*ROAD WORK*	*RAILROADS*
	90	*90*	*%*	*90*	*%*	*90*
# OF HAZARD/EMERGENCY SITUATIONS PER WEEK						
< 10	27	28	38	7	25	100
10-99	42	32	31	60	50	--
101+	31	40	31	33	25	--
MEAN SITUATIONS	**(216)**	**(216)**	**(196)**	**(359)**	**(193)**	(3)
ANNUAL BUDGET FOR HAZARD/EMERGENCY WARNING DEVICES						
< $5,000	**29**	**48**	**69**	**53**	**25**	**25**
$5,000-$49,999	**34**	**32**	**19**	**34**	**38**	**25**
$50,000+	**37**	**20**	**12**	**13**	**37**	**50**
MEAN BUDGET	***($72K)***	***($82K)***	***($40K)***	***($35K)***	***($22K)***	***($46K)***
AVERAGE PER CAPITA	**38¢**	**53¢**	**26¢**	**15¢**	**7¢**	**23¢**
(NOR)	**(73)**	**(25)**	**(16)**	**(15)**	**(8)**	**(4)**

[FHWA M-47]

INITIAL REACTION TO IVSAWS

■ While, nine out of ten Deployment Professionals like IVSAWS, most of the respondents selected "Like It Somewhat" over "Like It A Lot" as a response.

INITIAL REACTION TO IVSAWS						
DEPLOYMENT PROFESSIONALS						
	TOTAL	*POLICE*	*FIRE*	*PARAMEDICS/ AMBULANCE*	*ROAD WORK*	*RAILROADS*
	%	%	%	%	%	%
NET: LIKE IT	94	88	94	100	88	100
LIKE IT A LOT	21	24	19	33	13	--
LIKE IT SOMEWHAT	73	64	75	67	75	100
NET: DO NOT LIKE IT	6	12	6	--	12	--
(NOR)	(73)	(25)	(16)	(15)	(8)	(4)

[FHWA M-48]

WHY LIKE/DISLIKE IVSAWS

- No single reason dominates Deployment Professionals' reactions to IVSAWS. Rather, the diverse list illustrates the System means different things to most respondents.

WHY LIKE/DISLIKE IVSAWS DEPLOYMENT PROFESSIONALS	*TOTAL*	*POLICE*	*FIRE*	*PARAMEDICS/ AMBULANCE*	*ROAD WORK*	*RAILROADS*
	%	%	%	%	%	%
POSITIVE RESPONSES						
GOOD IDEA-HAS INTRINSIC VALUE	22	40	13	13	2.5	
HELPS PROTECT PUBLIC-THEY CAN AVOID HAZARDS	10	4	25	13		
GOOD APPLICATIONS-MULTIPLE USES	7	16	–	7		
HELPS CREWS PICK ROUTES-GOOD FOR OUR EMERGENCY RE-SPONSE	6	8	–	20		
LIKE MAP FEATURE	2	8	–			
NEGATIVE RESPONSES						
NOT SURE/NEED MORE INFO	19	12	19	13	25	50
COST OBSTACLE TO AGENCIES	15	12	13	13	38	25
ONLY GOOD IF EVERYONE HAS IT	14	16	19	7	13	--
IN-CAR DISTRACTIONS TO PUBLIC	8	4	6	20	13	--
LITTLE VALUE FOR OUR NEEDS	7	4	13		13	25
PUBLIC WONT PAY	6	4	–	7		25
IMPLEMENTATION CONFUSION	4	4	6			25
GIMMICK-TOY	3	4	–			
(NOR)	(73)	(25)	(16)	(15)	(8)	(4)

PERCEIVED DEPLOYMENT TIME

- Overall, two-thirds of the Deployment Professionals feel it should take one minute, or less, to deploy IVSAWS.
- All feel their staff could operate/deploy the System after proper training.

PERCEIVED DEPLOYMENT TIME						
DEPLOYMENT PROFESSIONALS						
	TOTAL	*POLICE*	*FIRE*	*PARAMEDICS AMBULANCE*	*ROAD WORK*	*RAILROADS*
	%	%	%	%	%	%
1 MINUTE OR LESS	66	64	75	80	38	75
2-3 MINUTES	23	24	25	13	38	--
4+ MINUTES	11	12	--	7	24	25
(NOR)	(73)	(25)	(16)	(15)	(8)	(4)

[FHWA M-50]

REACTIONS TO SPECIFIC OPTION FEATURES

- All of the specific features listed below elicit a positive reaction, except Disposable Transmitters.

REACTIONS TO SPECIFIC OPTIONAL FEATURES						
DEPLOYMENT PROFESSIONALS						
	TOTAL	POLICE	FIRE	PARAMEDICS/ AMBULANCE	ROAD WORK	RAILROADS
	%	%	%	%	%	%
REMOTE CONTROL DISPATCH CENTERS						
YES	69	64	75	60	75	75
NO	31	36	25	40	25	25
DISPOSABLE TRANSMITTERS						
EXCELLENT IDEA	19	42	25	40	13	25
GOOD IDEA	26	68	25	27	38	
POOR IDEA	55		50	33	50	75
ON-SITE UPDATES						
EXCELLENT IDEA	50	56	25	40	75	75
GOOD IDEA	38	36	63	33	13	25
POOR IDEA	12	8	12	27	12	--
MAY DAY FUNCTIONS						
EXCELLENT IDEA	41	44	6	67	38	75
GOOD IDEA	38	40	63	13	37	--
POOR IDEA	21	16	31	20	25	25
AUTOMATIC THEFT DETECTION						
EXCELLENT IDEA	52	72	25	60	25	75
GOOD IDEA	27	16	38	20	50	
POOR IDEA	21	12	37	20	25	25
						1
(NOR)	(73)	(25)	(16)	(15)	(8)	(4)

[FHWA M-51]

USER INTERFACE ISSUES OF CONCERN

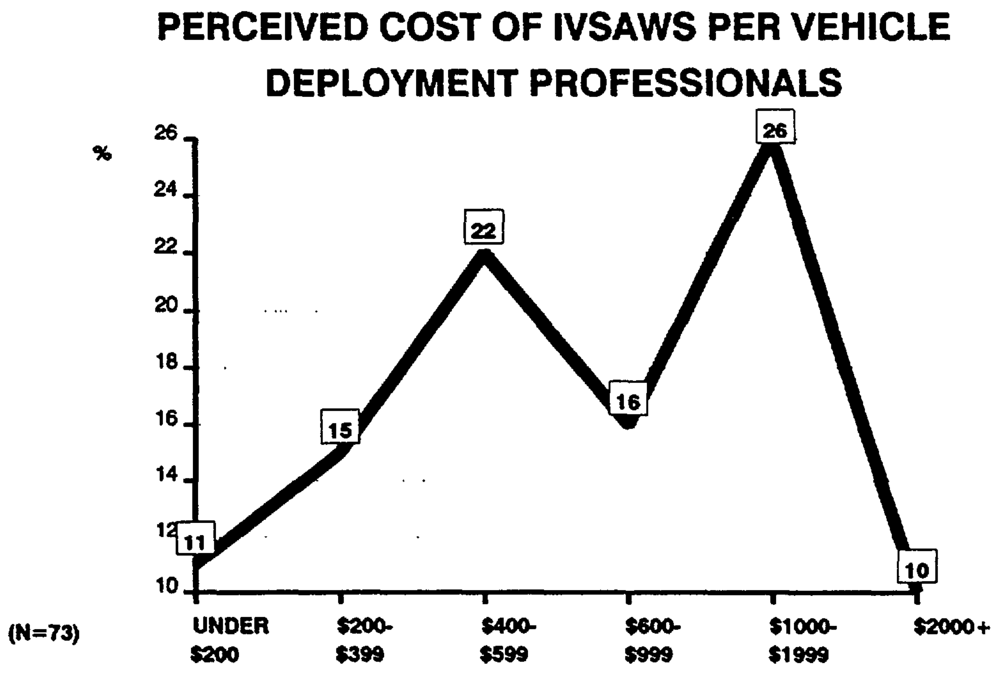
- The biggest concerns are related to space and location in the vehicle.
- Compatibility with current Systems and different vehicles concerns one in four respondents.
- Most other interface issues are of concern to less than 10% of the sample.

USER INTERFACE ISSUES OF CONCERN						
DEPLOYMENT PROFESSIONALS						
	TOTAL	*POLICE*	*FIRE*	*PARAMEDICS/ AMBULANCE*	*ROAD WORK*	*RAILROADS*
	%	%	%	%	%	%
SPACE IN VEHICLES	43	56	44	47	--	--
COMPATIBILITY WITH CURRENT SYSTEMS &/OR DIFFERENT VEHICLES	25	16	31	20	25	75
LOCATION IN VEHICLE	18	32	6	13	13	--
COST	12	8	13	13	25	--
POWER/BATTERY LIFE	8	--	6	33	--	--
USER FRIENDLY INPUT	7	12	6	--	--	25
DISTRACTING	6	--	19	--	--	--
DURABILITY/LOW MAINTENANCE	5	4	6	13	--	--
DEPLOYMENT EASE	3	4	--	--	13	--
ALL OTHER (SINGLE MENTIONS)	13	12	13	7		25
NEED MORE INFO	10	4	19	7	25	--
NO PROBLEMS	5	4	--		13	
(NOR)	(73)	(25)	(16)	(15)	(8)	(4)

[FHWA M-52]

PERCEIVED COST OF IVSAWS PER VEHICLE

- One in three Deployment Professionals feel the IVSAWS will cost $1000 or more per vehicle.
- One in four Deployment Professionals consider IVSAWS to be worth under $400.
- Deployment Professionals expect an IVSAWS to cost an average of $900.



[FHWA M-53]

INTEREST IN SEEING DEMONSTRATION OF IVSAWS

- More than eight in ten Deployment Professionals want to see a working demonstration.
- Enthusiastic interest ("extremely") is lowest among Fire Department Evaluators.

INTEREST IN SEEING IVSAWS DEMONSTRATION						
DEPLOYMENT PROFESSIONALS						
	TOTAL	*POLICE*	*FIRE*	*PARAMEDICS/ AMBULANCE*	*ROAD WORK*	*RAILROADS*
	%	%	%	%	%	%
NET: INTERESTED	84	84	69	86	88	100
EXTREMELY	36	32	13	54	50	25
SOMEWHAT	48	52	56	33	38	75
NET: NOT INTERESTED	16	16	31	13	12	--
(NOR)	(73)	(25)	(16)	(15)	(8)	(4)

[FHWA M-54]

REASONS FOR/AGAINST IVSAWS DEMONSTRATION

- Several Deployment Professionals say they need to see the system work They want first hand experience.
- No other issues dominate this groups' responses.

REASONS FOR/AGAINST IVSAWS DEMONSTRATION				
DEPLOYMENT PROS				
	INTEREST IN SEEING DEMONSTRATION			
	TOTAL	**EXTREME**	**SOMEWHAT**	**NONE**
REASONS..	+%	%	%	%
NEED TO SEE IT WORK	23	27	29	--
NEED MORE INFORMATION	16	4	29	8
INTERESTING, PROMISING, USE-FUL, GOOD TOOL	16	39	6	--
BUDGET CONSTRAINTS	16	4	26	17
NO NEED FOR IVSAWS	11	--	6	50
STAY UP-TO-DATE	6	4	9	--
MAKES OUR JOB SAFER/ MORE EFFECTIVE	6	15	--	..
RESEARCHING SIMILAR PROCESSES	4	12	--	--
ALL OTHER (SINGLE MENTIONS)	15	12	17	24
(NOR)	**(73)**	**(26)**	**(35)**	**(12)**

[FHWA M-55]

DDITIONAL QUESTIONS/CONCERNS ABOUT IVSAWS

[] No single question preoccupies Deployment Professionals.

[] Two in ten have questions about cost.

[] Almost four in ten said they have no additional questions at all.

ADDITIONAL QUESTIONS/CONCERNS ABOUT IVSAWS						
	DEPLOYMENT PROFESSIONALS					
	TOTAL	*POLICE*	*FIRE*	*PARAMEDICS/ AMBULANCE*	*ROAD WORK*	*RAILROADS*
	%	%	%	%	%	%
QUESTIONS/CONCERNS:						
COST	19	24	13	20	38	--
NEED MORE INFO/DEMO	14	12	19	13	13	--
REPAIRS & MAINTENANCE ISSUES	8	--	6	20	25	--
JURISDICTION OF SIGNALS	8	8	--	20	13	--
UP-DATES (HOW OFTEN?)	6	--	6	--	25	25
PUBLIC MUST BUY INTO IVSAWS	6	4	6	7	13	--
HOW W-ILL IT WORK IN URBAN AREAS?	4	--	13	—	13	--
SIZE OF EQUIPMENT	3	4	—	7	--	--
AU OTHER (SINGLE MENTIONS)	19	20	19	27	2.5	--
NONE/NO QUESTIONS	37	40	38	27		75
(NOR)	(73)	(25)	(16)	(15)	(8)	(4)

[FHWA M-56]

SOME ADDITIONAL COMMENTS ABOUT UTILITY WEIGHTS...

IVSAWS shoppers will make purchase decision by weighing their options. They will compare and contrast alternatives based upon the factors that are most important to them at the time.

For this survey we selected several levels of product/features and pricing alternatives to represent the scope of purchase considerations. Thirty-two decision factors were isolated (see below). Each one has a particular value (weight) for each customer...representing how much he/she wants it. The heavier the weight the more it influences the final decision. The issues that are not important receive the lightest weights,

TRADE-OFF ATTRIBUTES - DEPLOYMENT PROFESSIONAlS
(Version 1.0 July 14. 1992)

******* Attribute # 1 *******

1 ALERT: Video Display u/Icons
2 ALERT: Video Display W/map of hazard & your car's location
3 ALERT: Speech Synthesized System
4 ALERT: Video Display v/icons AND Speech Synthesized System
5 ALERT: Video Display w/Map AND Speech Synthesized System

******* Attribute #2 *******

/+
1 Warning Distance: l/4 mile
2 Warning Distance: l/2 mile
3 WarningDistance: 3/4 mile
4 WarningDistance: 1 Mile
5 WarningDistance: 1 l/2 Miles

******* Attribute #3 *******

/+
1 No Self-Activated HAY-DAY Option
2 Has Self-Activated MY-DAY Option

******* Attribute # 4 *******

1 Has Automatic Theft Detection & Location Reporting to Police
2 No Stolen Vehicle Detection or Reporting Capabilities

******* Attribute #5 *******

/ -
1 Purchase Price: $300 per vehicle
2 Purchase Price: S400 per vehicle
3 Purchase Price: $500 per vehicle
4 Purchase Price: $600 per vehicle
5 Purchase Price: $700 per vehicle

******* Attribute #6 *******

1 Made by: American Car Co.
2 Made by: Japanese Electronics Co
3 Hade by: IBM
4 Made by: Military Radar and Gurdance System Co.

******* Attribute # 7 *******

/ -
1 Deployment time: 30 seconds
2 Deployment time: 1 minute
3 Deployment time: 2 minutes
4 Deployment time: 3 minutes

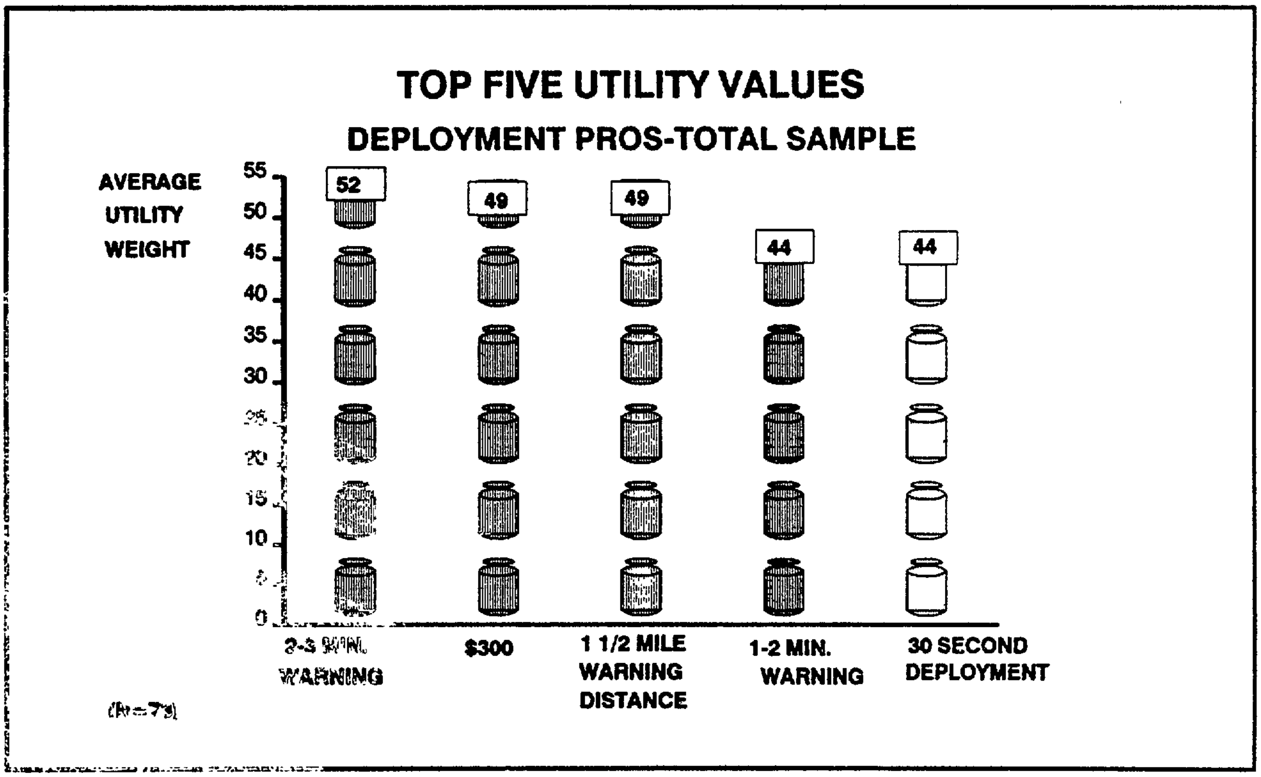
******** Attribute # 8 *******

/+
1 Warning Time: l0-20 seconds before hazard
2 Warning Time: 20-40 seconds before hazard
3 Warning Time: 40-60 seconds before hazard
4 Warning Time: l-2 minutes before hazard
5 Warning Time:2-3 minutes before hazard

[FHWA M-57]

MOST IMPORTANT ISSUES – TOP FIVE UTILITY VALUES

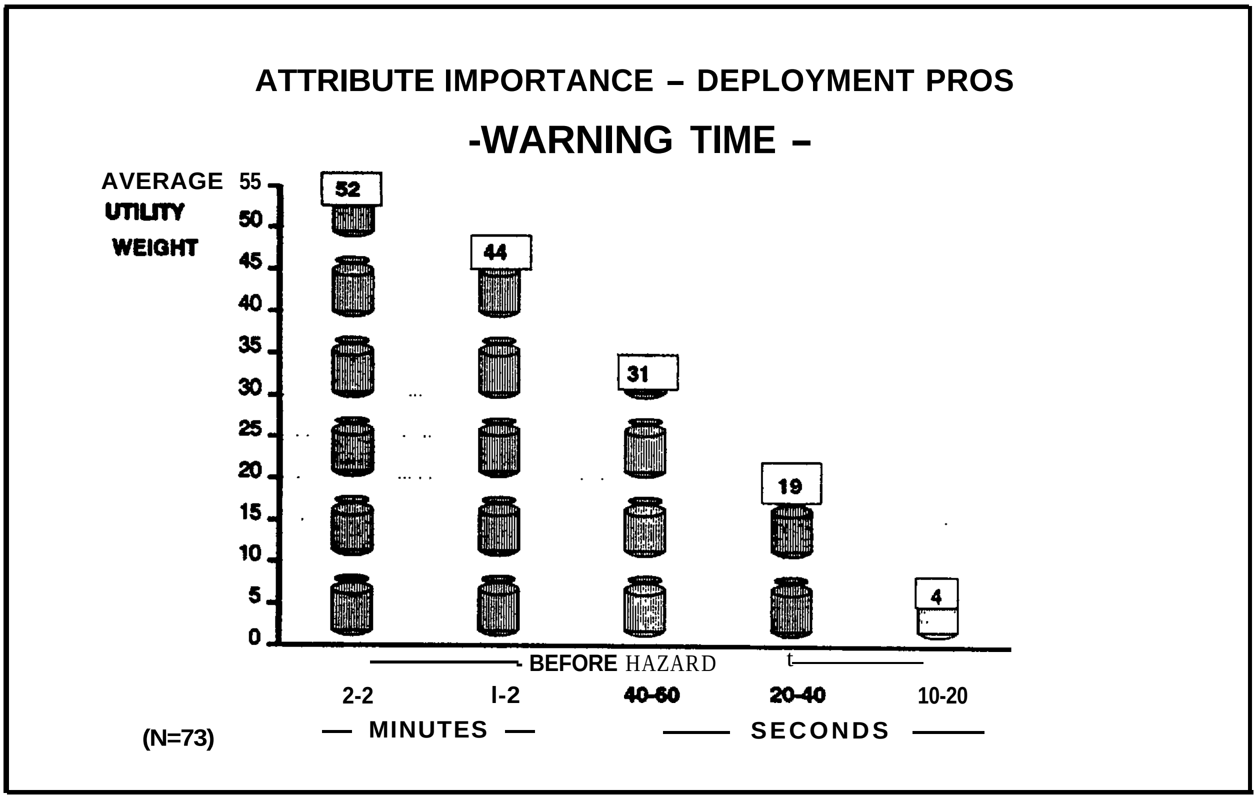
- Adequate pre-hazard alert time and distance are extremely important (three of top five) to Deployment Agencies.
- Lowest possible system costs are another major desire.
- Fast deployment is also one of the five most important issues.
- Importance/Utility Values are basically the same between different types of Deployment Agencies.



[FHWA M-58]

RELATIVE IMPORTANCE OF WARNING TIME

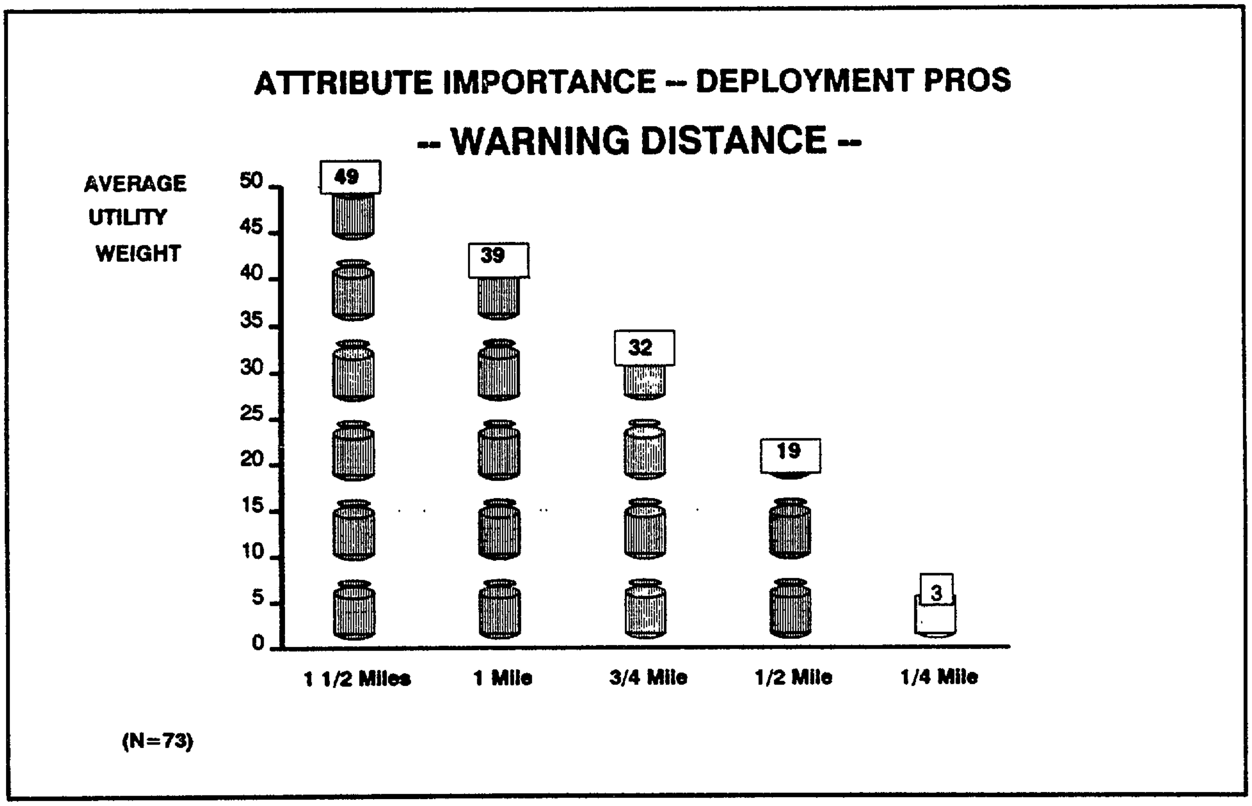
- The Deployment Agencies want, and feel very strongly about, two to three minutes of alert time.
- The cross-tabulations indicate paramedics and ambulance companies value Warning Time the most.



[FHWA M-59]

RELATIVE IMPORTANCE OF WARNING DISTANCE

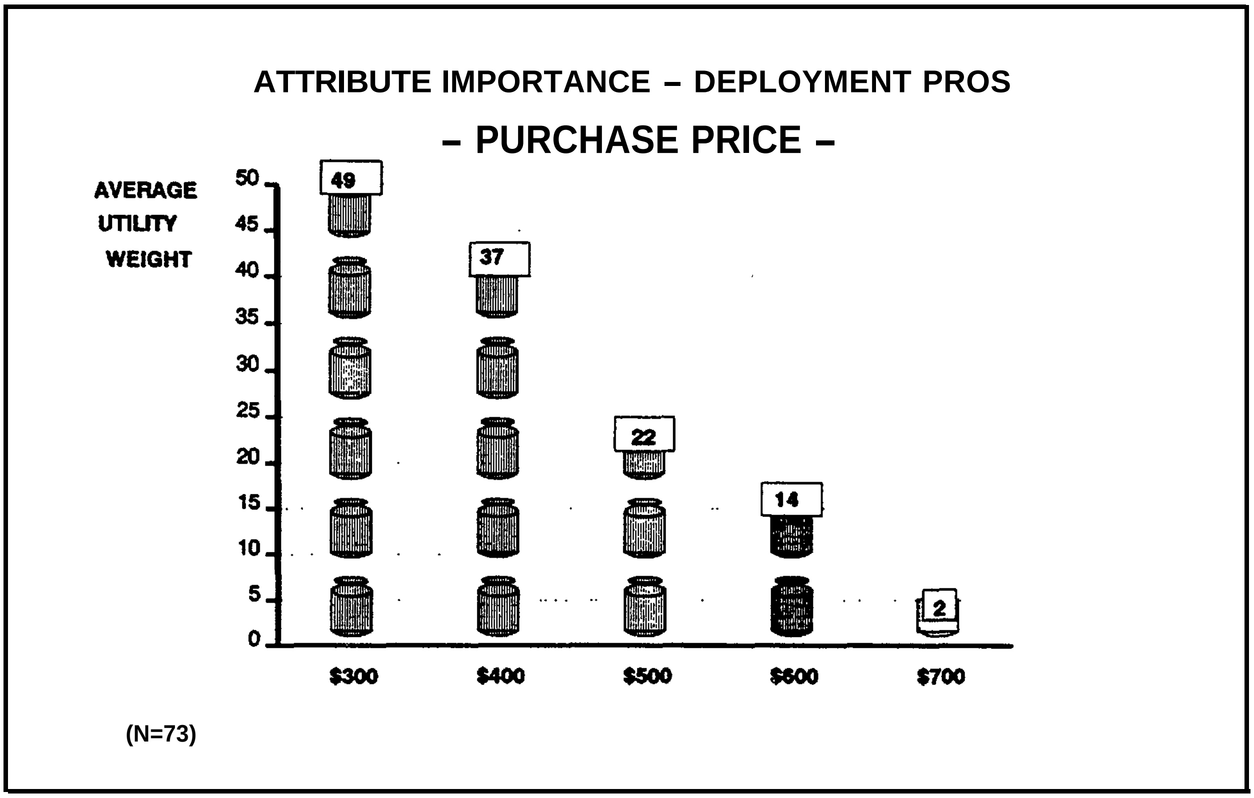
- Pre-hazard alerts should be one and one-half miles away from the emergencies.
- Warning Distance is closely correlated to Warning Time...the earlier the better.



[FHWA M-60]

RELATIVE IMPORTANCE OF PURCHASE PRICE

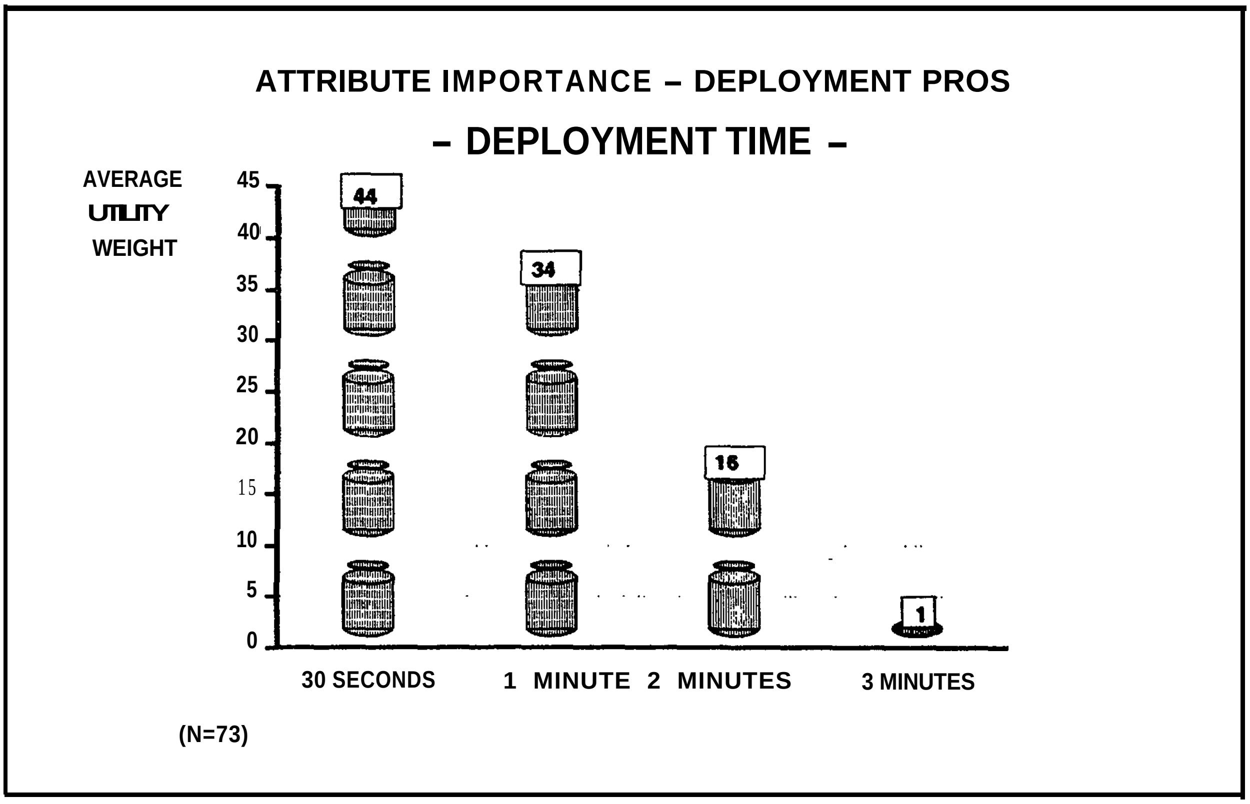
- Getting the "most for the least" is very important to Deployment Agencies. This is especially true during the prolonged recession in Western states.
- A $400 System is two and one-half times more appealing than the same System at $600 (37: 14 = 2.6),assuming all else is equal.



[FHWA M-61]

RELATIVE IMPORTANCE OF DEPLOYMENT TIME

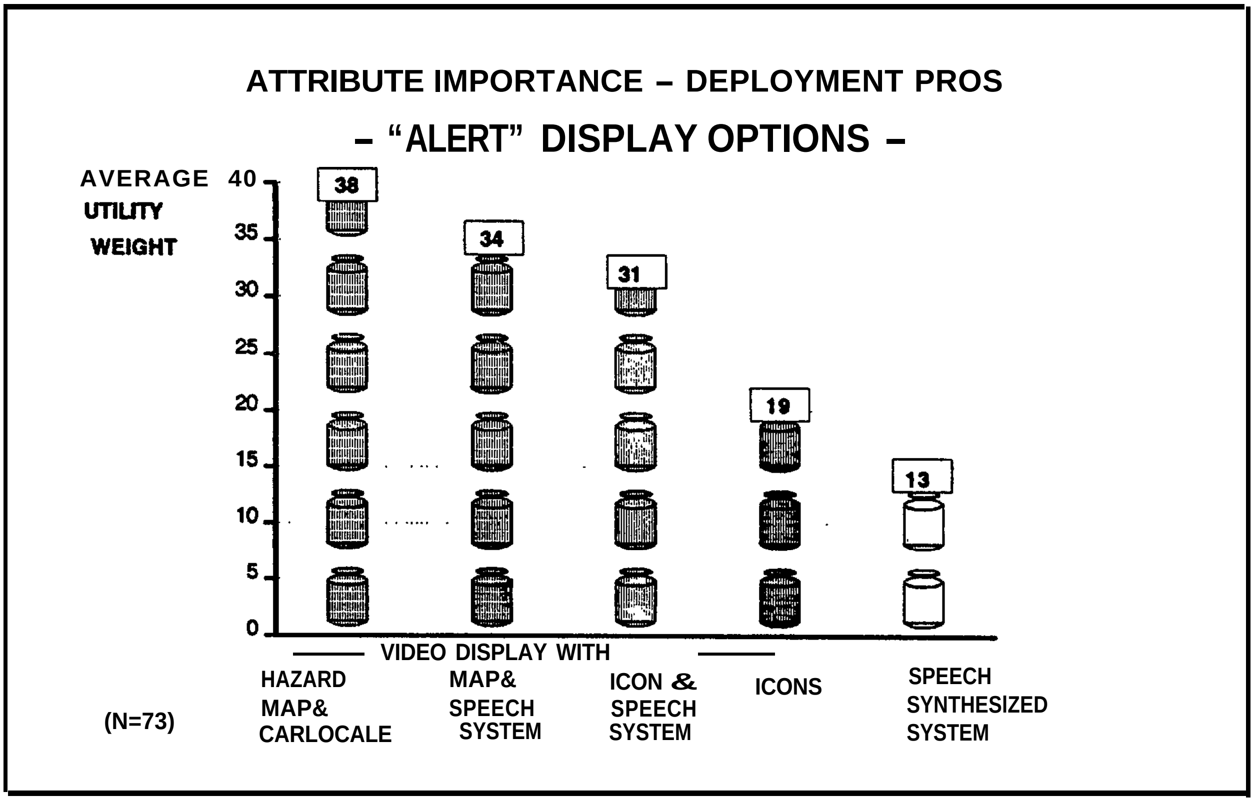
- "The quicker the better," is desired by all the Deployment Agencies.
- A "one minute" System is twice as valuable as a "two minute" System (34:16 = 2.1), assuming all else is equal.
- The cross-tabulations indicate Paramedics/Ambulance Companies put a special premium on fast deployment.



[FHWA M-62]

RELATIVE IMPORTANCE OF "ALERT" DISPLAY OPTIONS

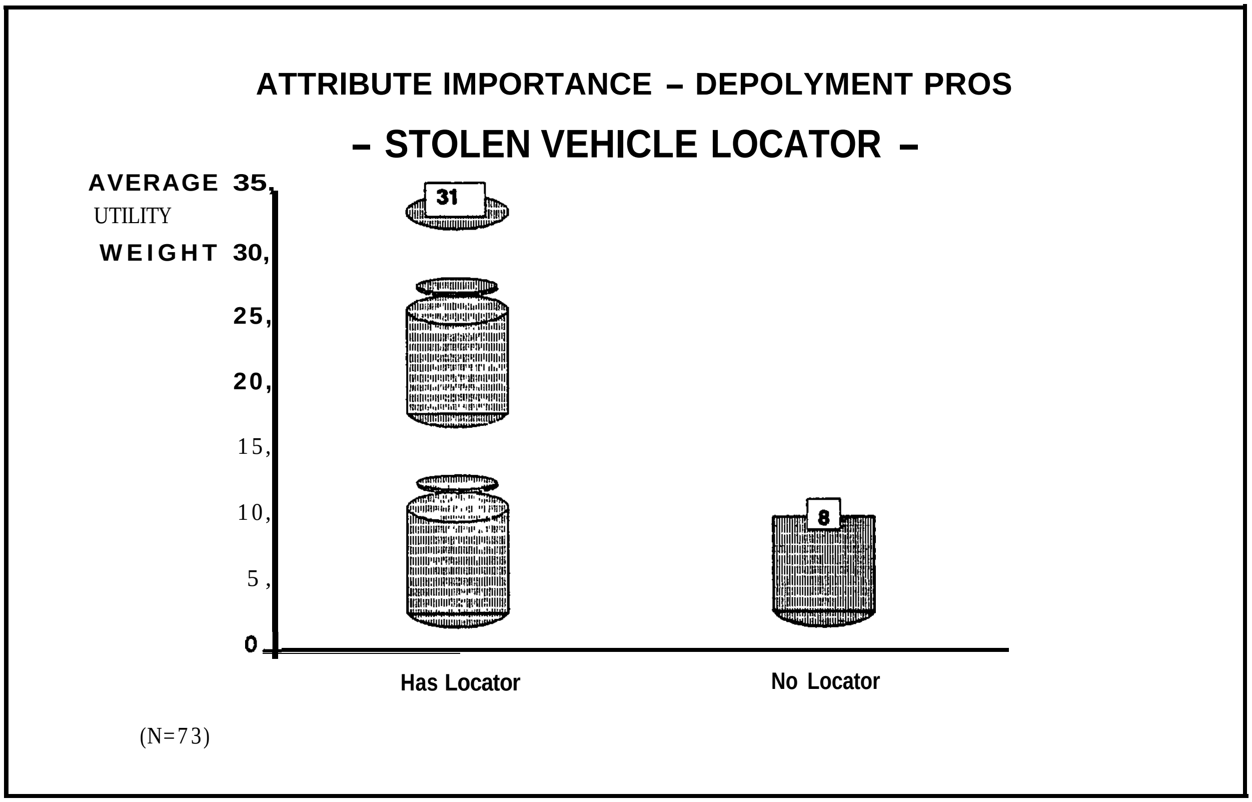
- Single display options (Icons or Speech) are not very attractive when multiple display options are available.
- The Hazard Map and Vehicle Location Option is the overall favorite.
- A System with video, map and speech is valued slightly more than the video, icon and map version.



[FHWA M-63]

RELATIVE IMPORTANCE OF STOLEN VEHICLE LOCATOR

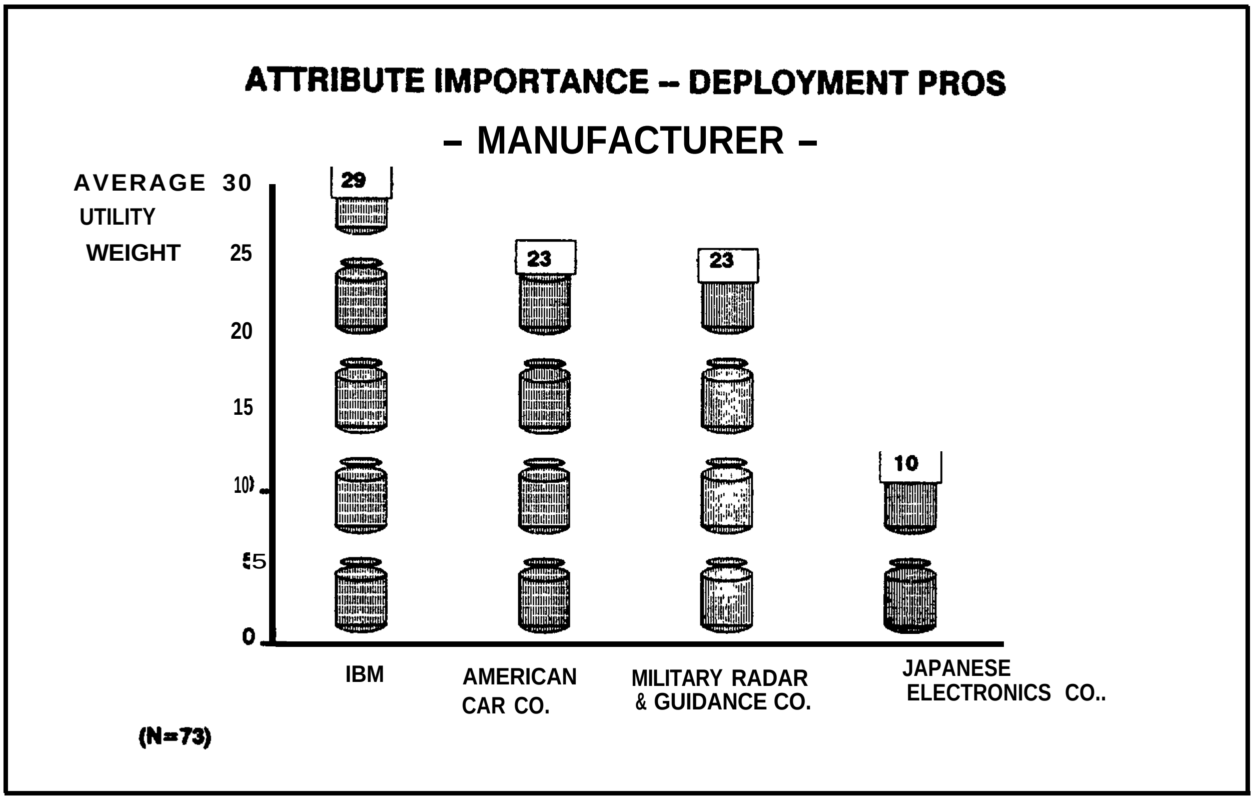
- This option, while desirable, is not one of the primary attributes for Deployment Agencies.
- Law enforcement evaluators place twice the value (48) as do all the others combined (22).



[FHWA M-64]

RELATIVE IMPORTANCE OF MANUFACTURER

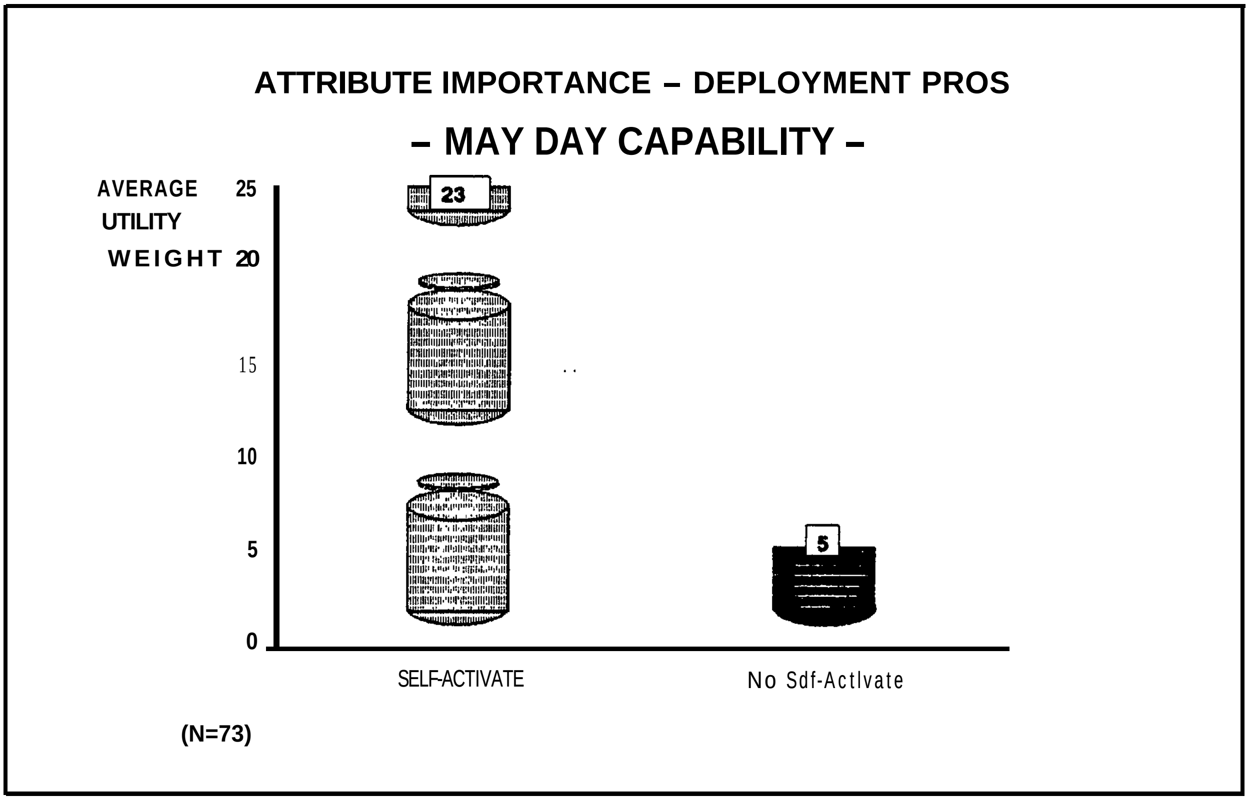
- Deployment Agencies want to buy "American.,"
- IBM has slightly more value than the other two U.S.A. remaining options.



[FHWA M-65]

RELATIVE IMPORTANCE OF SELF-ACTIVATED MAY DAY CAPABILITY

- Deployment Agencies place less emphasis on this feature than most other options.
- Cross-tabulations reveal Paramedics/Ambulance Companies and Law Enforcement favor this feature the most.



[FHWA M-66]

PRODUCT DEFINITIONS

TRADE-OFF SIMULATIONS - THE SEARCH FOR THE BEST WAY TO DESIGN AND PRICE IVSAWS

Once a customer's utility weights are established, it is possible to see which combination of features has the highest overall value. We refer to this process as simulating alternative scenarios. In essence, a simulation produces a "pie chart" where each product's relative appeal is represented by the size of the "slice."

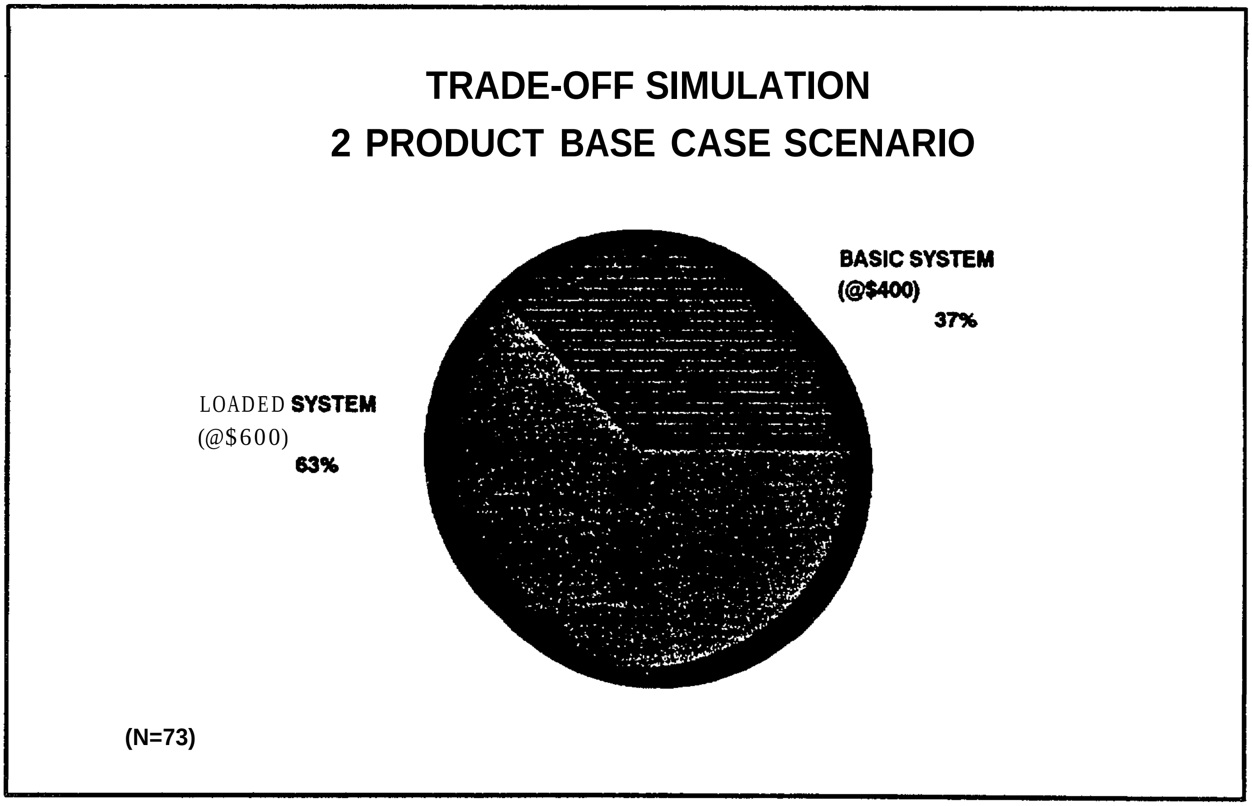
We start this process by establishing a BASE CASE...a basic set of product definitions. Two configurations, Basic and Loaded, were designated to represent a BASE CASE environment for IVSAWS. A Mid-Range System will be introduced later with the definitions shown below.

PRODUCT DEFINITIONS			
DEPLOYMENT PROFESSIONALS			
	BASIC SYSTEM	***LOADED SYSTEM***	***MID-RANGE SYSTEM***
ATTRIBUTES:			
ALERT	VIDEO WITH ICONS	VIDEO WITH MAP & VOICE	VIDEO WITH ICONS & VOICE
WARNING DISTANCE	1 MILE	1 1/2 MILES	1 1/4 MILES
MAY DAY	NONE	YES	YES
THEFT DETECTION	NONE	YES	NO
PRICE	$400	$450	$350
MANUFACTURER	AMERICAN CAR CO.	MILITARY SYSTEM	MILITARY SYSTEM
DEPLOYMENT TIME	1 MINUTE	1 MINUTE	1 MINUTE
WARNING TIME	1-2 MINUTES	2-3 MINUTES	2 MINUTES

[FHWA M-67]

MARKET SHARE ESTIMATES - TWO PRODUCT BASE CASE SCENARIO

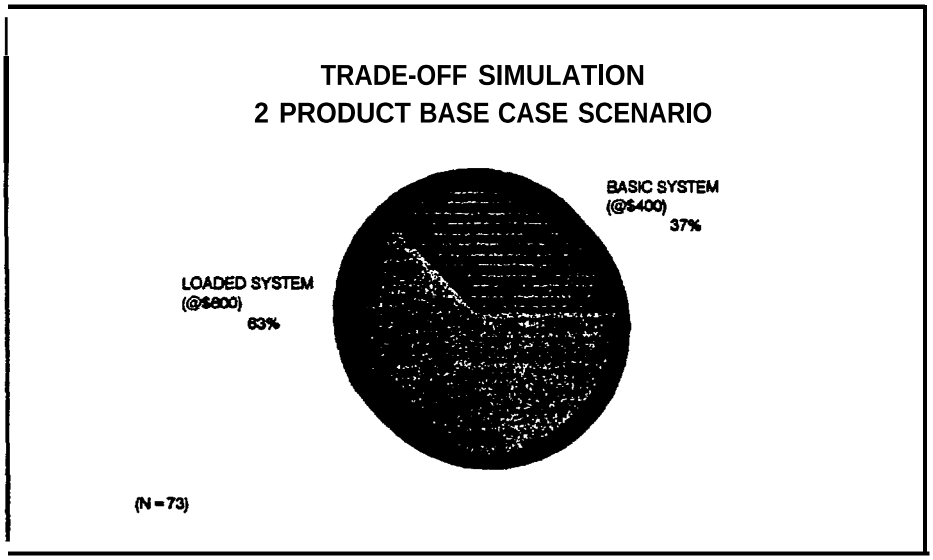
- The "Loaded" IVSAWS is almost twice as appealing as the Basic Unit. This pattern is similar across sub-groups.

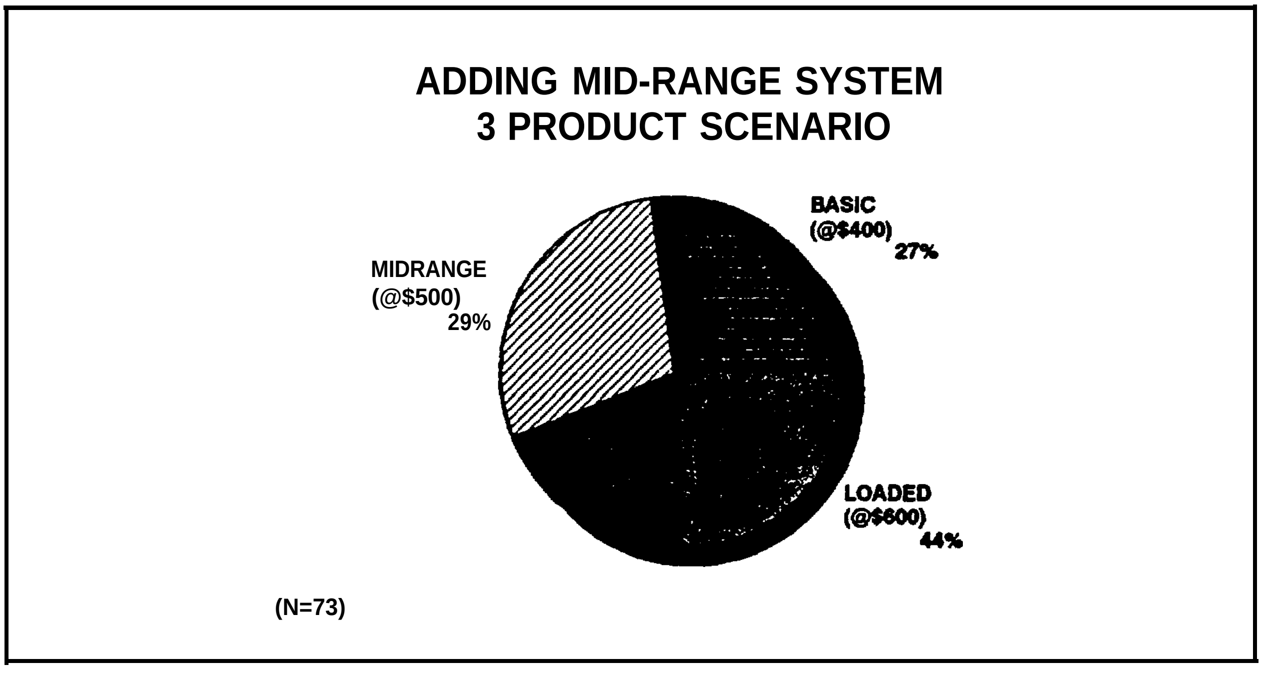


[FHWA M-68]

<u>"WHAT IF?" IMPACT OF ADDING A MID-RANGE SYSTEM</u>

- The Mid-Range System has a "preference share" of almost 30%.
- The Loaded System is still preferred more than the other two systems.
- The Loaded System at $700 losses only 6% of its appeal.





APPENDIX

[FHWA M-70]

TRAFFIC HAZARD AND EMERGENCY WARNING SYSTEM (THEWS)

THEWS is a safety advisory warning system that is applicable to roadway hazards on rural, urban, primary and secondary highways. THEWS identifies advisory, safety and hazard situations for motorists, and provides an in-vehicle advisory to drivers in advance of roadway hazards.

THEWS will use radio transmitters placed at or near roadway hazards to communicate advisories and/or warnings to approaching vehicles equipped with radio receivers. The system will be capable of functioning as a stand-alone communicator (direct roadside to vehicle communication) and as part of an Intelligent Vehicle Highway System (IVHS).

The highway safety problems to which THEWS is applicable include: accidents,- fast approaching emergency vehicles, road construction jobs, railroad grade crossings, slow moving vehicles on highways, rock slide areas, fog, icy bridges, etc.

DISCUSSION GUIDE-TRADE-OFF FOCUS GROUPS

TRAFFIC HAZARD & EMERGENCY WARNING SYSTEM

1. INTRODUCTION (I0 MINUTES)

1A. Explain purpose of session. Read Levitt quote.

1B. Discuss ground rules and encouragement to share honest feedback.

1C. Introduction: (Name, occupation, family composition, car ownership, cellular ownership, recent traffic tie-up experiences.)

2. DISCUSSION OF DRIVING APPLICATIONS (10 MINUTES):

2A. How do you use your automobile?

Specifically..

Do you drive to work? How far?

Do you drive in the city/country/mountains/desert?

Spouse & children's driving patterns?

2B. Are you the *exclusive* user of vehicle of do you share?

3. <u>INTRODUCE CONCEPT ILLUSTRATIONS:</u>

4. <u>DISCUSS "PONDERING YOUR CHOICES" RESPONSE SHEET (10 minutes)</u>

4A. Probe for important product consideration. Differentiate the issues consumers will use to select &/or reject.

4B. Explore fears and concerns about purchasing a warning/alert system.

4c. Establish overall reactions..purchase intentions.

Discuss and probe for...

* perceived importance/applicability

* strengths

* weaknesses

• desire to have

primary barriers to acceptance

5. <u>DETERMINE SENSITIVITY OF DRIVERS TO FALSE ALARMS(10 MINUTES)</u>

5A. Irrelevant warning messages...

a. Messages intended for vehicles traveling in opposite direction on same road.

b. Messages intended for a different road.

c. Warning message for vehicles traveling overpass received while traveling underpass.

d. Old message received (i.e., hazardous situation has dissipated but warning messages for hazard still being generated by IVSAWS transmitter).

5B. Relevant but premature warning messages (i.e., hazard is five miles down the road).

5C. Relevant but late warning messages (i.e., too late to make successful hazard avoidance maneuver).

5D. Nonsense messages (i.e., "WRBFH#$1878)

6. GAUGE WARNING EFFECTIVENESS PERIOD (5 MINUTES)

6A. How soon is too soon to receive a warning message (baseline design is 6 seconds before encountering hazard).

7. MAYDAY FUNCTION (5 minutes)

7A. Do drivers want a mayday function (i.e., driver can turn on an "electronic flare" when car is disables &/or represents a hazard to other motorists).

7B. How much extra would the driving public pay for this feature?

8. COST DETERMINATION (10 MINUTES)

8A. In general, how much is driver willing to pay for an IVSAWS?

8B. Given two otherwise identical cars, one equipped with IVSAWS & one not, would drivers be more likely to buy the IVSAWS equipped vehicle (at additional cost)?

9. AVAILABILITY (5 MINUTES)

9A. If an integral IVSAWS unit was available as part of a new car purchase (including DNA & DIS) would drivers most likely:

a. Wait for next new vehicle purchase to get IVSAWS

b. Buy a lower cost retrofit or portable unit

9B. If an integral unit was not available as part of a new car purchase would drivers most likely:

a. Wait until IVSAWS was available as part of a new vehicle purchase (including DNA & DIS)

b. Buy a retrofit or portable unit

9c. IVSAWS may initially be available only in certain areas (analogy--cellular telephone). In a timed deployment, where would drivers want it available?

a. First in a rural driving environment, or

b. An urban driving environment

10. ANTENNAS (5 MINUTES)

10A. Are drivers sensitive to having an IVSAWS antenna placed on their vehicle? IF SO, HOW BIG IS TOO BIG?

11. WARNING PRESENTATION FEATURES (5 MINUTES) -- Ranking Sheet

12. SITUATIONS WHERE IVSAWS WOULD BE MOST USEFUL (5 MINUTES)
Ranking Sheet

13. TRADE-OFF SURVEY (25 MINUTES):

13A. Explain the process and review attribute definitions

13B. Administer computer interview

13C. Discuss what was learned from process...Things values most?...What consumer will give up to get?

13D. Discuss price elasticities. Probe for things worth paying more for. What would tip your decision scale?

14. FUTURE PURCHASE? - FORCE DECISIONS (10 MINUTES):

14A. Will you buy? For whom and what vehicle (current vs. future)?

14B. Buy alone or part of a "new vehicle package?" Probe value of same brand as vehicle.

14C. Outlet? Why/why not new car dealership?

14D. Probe importance of service contracts, return policies, manufacturer support.

15. FINAL QUESTIONS FORM "BEHIND THE MIRROR- (5 MINUTES)

Name ____________________

Date ____________________

Please number . . . 1, 2, 3, etc... in their order of importance to you, the following warning presentation features. Place a " 0" on the linels next to the features that hold no Importance to you.

____ Ability to disable reception of all warning messages.

____ Text display of warning messages.

____ Entertainment system suppression.

____ Ability to selectively disable particular warning messages.

____ Layered warnings (i.e., driver first gets a very brief hazard warning message or icon and can request more detailed information).

____ Icon display of hazard type.

____ Street map display with location of vehicle and hazard identified.

____ Message repeat function.

Synthesized speech warning messages.

Name ____________________

Date ____________________

Pretend you found yourself in the following situations. Please indicate, in the spaces provided, how useful you think the Traffic Hazard/Alert System would be.

1. Signaling emergency vehicle presence.

[] Extreme/y Useful [] Somewhat Useful [] Not Useful

2. Signaling that driver is approaching a railroad crossing.

[] Extremely Useful [] Somewhat Useful [] Not Useful

3. Signaling that a train is on or approaching the driver's path.

[] Extreme/y Useful [] Somewhat Useful [] Not Useful

4. Signaling an approaching crash site.

[] Extremely Useful [] Somewhat Useful [] Not Useful

5. Signaling an approaching crash site under low visibility conditions (fog or dust).

[] Extremely Useful [] Somewhat Useful [] Not Useful

6. Supplemental traffic information (i.e., approaching a crosswalk, approaching a sharp curve in a road, approaching a deer crossing, narrow bridge ahead).

[] Extremely Useful [] Somewhat Useful [] Not Useful

7. Signaling that driver is approaching a stopped school bus or other special vehicle (i.e., farm vehicle).

[] Extremely Useful [] Somewhat Useful [] Not Useful .

8. Signaling that driver is approaching a roadside work zone.

[] Extremely Useful [] Somewhat Useful [] Not Useful

9. Signaling that driver is traveling too fast for current road conditions.

[] Extremely Useful [] Somewhat Useful [] Not Useful

10. Signaling the presence of a vehicle with its air bag deployed.

[] Extremely Useful [] Somewhat Useful [] Not Useful

TRADE-OFF ATTRIBUTES -- DEPLOYMENT PROFESSIONALS
(Version 1.0 July 14, 1992)

******* Attribute # 1 *******

ALERT: Video Display w/Icons

ALERT: Video Display w/Map of hazard & your car's location

ALERT: Speech Synthesized System

ALERT: Video Display w/icons AND Speech Synthesized System

ALERT: Video Display w/Map AND Speech Synthesized System

****** Attribute # 2 *******

Warning Distance: l/4 mile

Warning Distance: l/2 mile

Warning Distance: 3/4 mile

Warning Distance: 1 Mile

Warning Distance: 1 l/2 Miles

******* Attribute # 3 *******

No Self-Activated MAY-DAY Option

Has Self-Activated MAY-DAY Option

******* Attribute # 4 *******

Has Automatic Theft Detection & Location Reporting to Police

No Stolen Vehicle Detection or Reporting Capabilities

******* Attribute # 5 *******

-

Purchase Price: $300 per vehicle

Purchase Price: $400 per vehicle

Purchase Price: $500 per vehicle

Purchase Price: $600 per vehicle

Purchase Price: $700 per vehicle

******* Attrbute # 6 *******

1 Made by: American Car Co.

2 Made by: Japanese Electronics Co

3 Made by: IBM

4 Made by: Military Radar and Guidance System Co.

******* Attribute # 7 *******

/-

1 Deployment time: 30 seconds

2 Deployment time: 1 minute

3 Deployment time: 2 minutes

4 Deployment time: 3 minutes

******* Attribute # 8 *******

/+

1 Warning Time: 10-20 seconds before hazard

2 Warning Time: 20-40 seconds before hazard

3 Warning Time: 40-60 seconds before hazard

4 Warning Time: l-2 minutes before hazard

5 Warning Time: 2-3 minutes before hazard

[FHWA M-92]

IVSAWS ATTRIBUTE LIST – GENERAL PUBLIC
(Version 1.2 July 9, 1992)

******* Attribute # 1 *******

1 ALERT: Video Display w/Icons

2 ALERT: Video Display w/Map of hazard & your car's location

3 ALERT: Speech Synthesized System

4 ALERT: Video Display w/icons AND Speech Synthesized System

5 ALERT: Video Display w/Map AND Speech Synthesized System

******* Attribute # 2 *******

/+
Warning Distance: l/4 mile

2 Warning Distance: l/2 mile

3 Warning Distance: 3/4 mile

4 Warning Distance: 1 Mile

5 Warning Distance: 1 l/2 Miles

******* Attribute # 3 *******

/+
1 No Self-Activated MAY-DAY Option

2 Has Self-Activated MAY-DAY Option

******* Attribute # 4 *******

1 Has Automatic Theft Detection & Location Reporting to Police

2 No Stolen Vehicle Detection or Reporting Capabilities

******* Attribute # 5 *******

/-
1 Purchase Price: $150

2 Purchase Price: $250

3 Purchase Price: $350

4 Purchase Price: $450

5 Purchase Price: $550

******* Attribute # 6 *******

1 Features: Basic System Only

2 Features: Entertainment System Suppression

3 Features: System ON/OFF switch on steering wheel

4 Features: Supports DNA and DIS (see illustrations)

5 Features: Distance to hazard/ problem (sound or picture)

******* Attribute # 7 *******

/-
1 False Alarms: 1 Per Month

2 False Alarms: 1 Per Week

3 False Alarms: 1 Per Day

4 False Alarms: Every 2 Hours

******* Attribute #8 *******

/+
1 Warning Time: lo-20 seconds before hazard

2 Warning Time: 20-40 seconds before hazard

3 Warning Time: 40-60 seconds before hazard

4 Warning Time: l-2 minutes before

5 Warning Time 2-3 minutes before hazard

[FHWA M-93]

APPENDIX N:
IVSAWS TASK B, SUBTASK 4 REPORT
(ENGINEERING CHANGE PROPOSAL 3, OPTION AA)
FUNCTIONAL DEFINITION

This appendix includes a definition of the functions to be embedded within a first-gerneration Invehicle Safety Advisory and Warning System (IVSAWS). The functional support required to establish an electronic warning zone around a roadway hazard or advisory site is specified. Likewise, the functions needed to present the warning or advisory data to a driver once a vehicle has penetrated an electronic warning zone are defined.

1. INTRODUCTION

This document defines the functions to be embedded within a first generation In-Vehicle Safety Advisory and Warning System (IVSAWS). Broadly, it specifies the functional support that is required to establish an electronic waming zone around a roadway hazard or advisory site. It also defines the functions needed to present the warning or advisory data to a driver once a vehicle has penetrated an electronic warning zone. The functional requirements are a product of the following six studies that were conducted as part of the IVSAWS program:

Situation Identification and Prioritization - This task identified candidate advisory, safety, and hazard situations using recent rural and urban highway accident data and input from transportation engineering specialists. The situations which could be helped by an IVSAWS were identified for further study. The results of this study are documented in the IVSAWS Task B Final Report.

Driver-Alert Warning System Design - The Driver-Alert Warning System (DAWS) represents the vehicular subsystem used to convey information concerning advisory, safety and hazard situations to the driver of the vehicle. The DAWS study used anthropometric analysis and mockups to evaluate the IVSAWS human-machine interface with respect to ease of IVSAWS message perception and correct driver response to warnings and advisories. The results of this study are documented in the IVSAWS Task E Final Report.

IVSAWS Communication Subsystem Architecture Tradeoff - This study evaluated candidate IVSAWS Communication Subsystem architectures with respect to the following set of evaluation criteria: 1) functionality of one-way versus two-way communications, 2) relative advantages and disadvantages between spread-spectrum and narrowband communications, 3) relative advantages and disadvantages between Global Positioning System (GPS) and two-way ranging, and 4) frequency allocation. The results are documented in the IVSAWS Engineering Change Proposal 2 Final Report.

IVSAWS Market Assessment - This study evaluated driver receptivity to the IVSAWS concept and identified purchase decision criteria and desired system features. The results of this study are documented in the report titled Market Potential Assessment of IVSAWS Among the General Public and Deployment Professionals.

IVSAWS Co cept Workshop - The initial hazard scenario identification (Task B) was performed by the University of Michigan Transportation Institute (UMTRI). This workshop was an opportunity to interact with a broader representation of the transportation community and cooperatively refine the preliminary IVSAWS applications. The workshop activities and results are documented in the IVSAWS Concept Workshop Report.

IVSAWSimmunltv Interviews - This study evaluated the deployment practicality of different IVSAWS operational concepts from the perspective of those individuals and agencies which might be responsible for establishing the warning zones. The results are documented in the report titled Assessment of IVSAWS Deployment Practicality.

The results from these studies provide the inputs to the systems engineering process used to develop and evaluate the IVSAWS functional requirements. When properly implemented into, the functional requirements should enable IVSAWS to fulfill its primary objective - increase the probability of correct driver response to hazardous roadway conditions. The systems engineering process used for the IVSAWS program is a hybrid of two systems engineering methods, Quality Function Deployment and Structured Requirements Specification.

2. METHODOLOGY

Quality Function Deployment (QFD) and Structured Requirements Specification (SRS) are two methods that can be used to aid product planning and ensure that key functions are identified and implemented into a product design. The process used to identify the IVSAWS functional requirements is an adaptation and combination of QFD and SRS.

This report is not a tutorial in either QFD or SRS. Without a top-level understanding of these methods (SRS is an 120 hour course at Hughes), many of the charts and figures contained in this document will confuse the reader and appear to have little relationship with each other. A tap-level understanding of QFD and SRS can be obtained by reading the following texts:

> Strategies for Real-Time System Specification, by Derek 1. Hatley and Irntiaz A. Pirbhai
>
> Better Designs in Half the Time, by Bob King

Subsections 2.1 and 2.2 are provided as an introduction to QFD and SRS.

2.1 Quality Function DepIoyment (QFD)

Figure 2. l-l shows the QFD design flow chart. However, QFD is more than a design plan. QFD starts with product planning and continues through the product life cycle, including customer support once a product has been introduced to the marketplace. It is a method for designing a product based upon customer demands in order to give the customer the best possible product.

Under this contract, the key deliverable to the Federal Highway Administration is a basic system design (or designs) that is (are) in sufficient detail to support prototype system development. No product will be built. That is, no deliverable hardware or software will be produced. Thus, IVSAWS QFD will end at product planning (see Figure 2. l-l).

Figure 2.1-2 shows QFD design flow as it has been tailored for IVSAWS. Due to fiscal constraints, schedule constraints, and the nature of the IVSAWS "product", some elements of the product planning design flow will not be applied to the IVSAWS design flow.

There is no product competing with IVSAWS. IVSAWS is a Government study program, not a system to be produced and sold by the Federal Highway Administration. Thus, there is no need to survey competing products and patent rights. As part of the NSAWS Communication Subsystem design task (Task C), existing systems will be examined in order to determine if they can be used or adapted for the IVSAWS. However, these systems will not be viewed as products competing for market share.

A quality study, draft product plan, process failure mode analysis, value engineering effort, and pre-design testing are beyond the scope of this phase of the IVSAWS program.

Market requirements have been derived from the six studies identified in Section 1. The IVSAWS Market Assessment is, in effect, the matrix data analysis. Thus, the IVSAWS QFD study begins with development of the quality table (Chart A- 1, Figure 2.1-2). The tables developed for the IVSAWS QFD are presented in Appendix A.

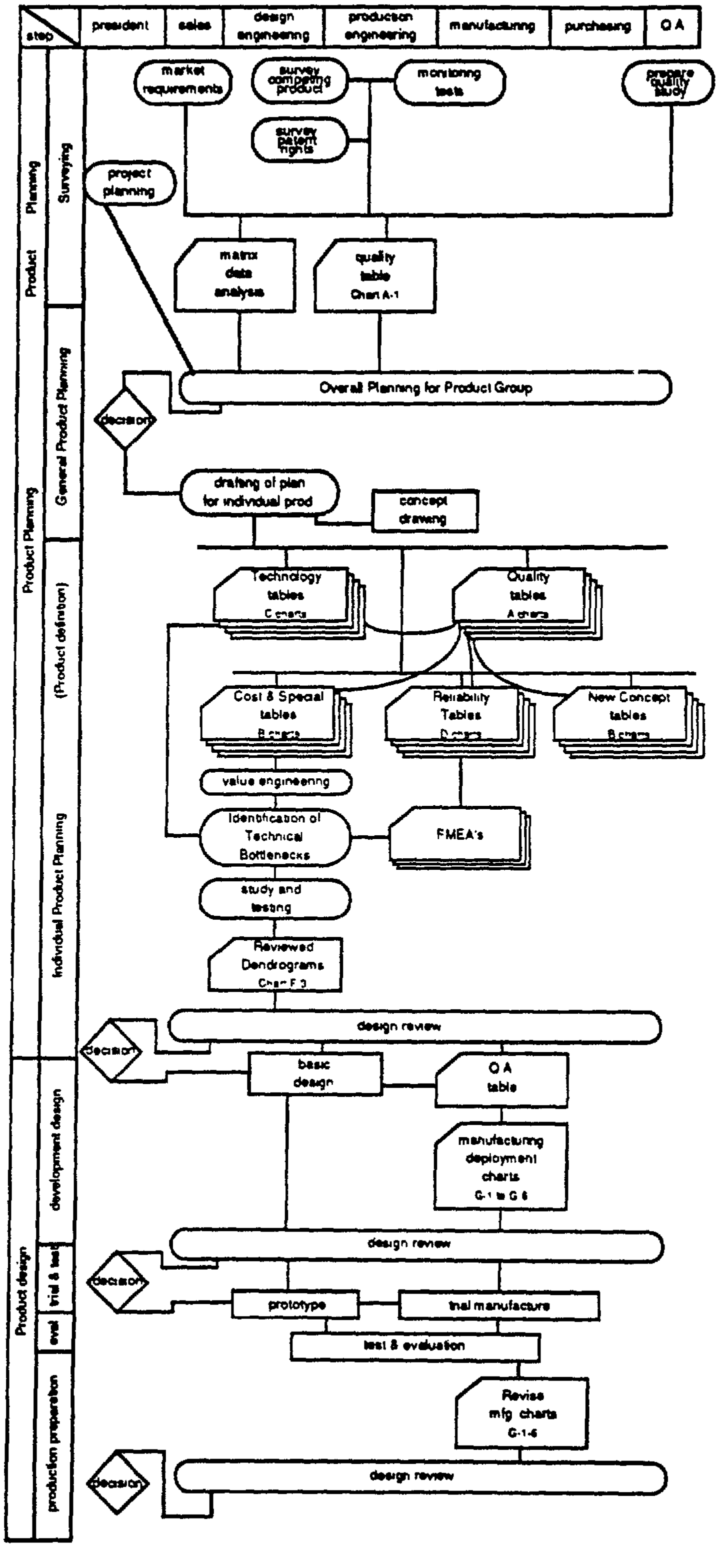


Figure 2.1-1. General QFD Design Flow Chart.[1]

[1]King, Bob, Better Designs in Half the Time, GOAL/QPC, Methuen, MA 01844, 1989, p.2-11.

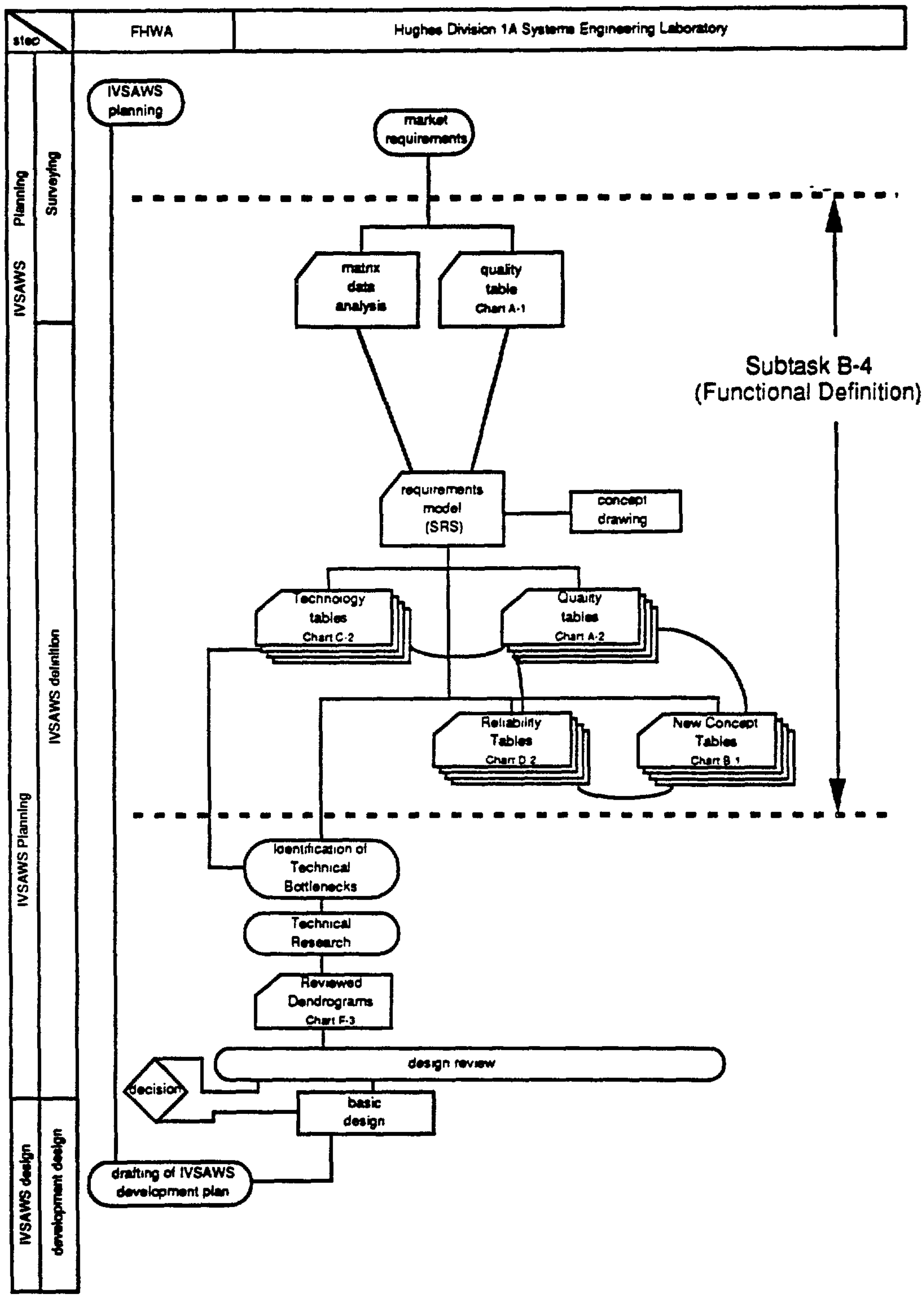


Figure 2.1-2. IVSAWS QFD Design Flow Chart.

2.2 Structured Requirements Specification (SRS)

The QFD charts used to perform the IVSAWS product definition compare IVSAWS functions with respect to customer demands, lVSAWS failure modes, quality characteristics, and subsystem components (mechanisms). Candidate IVSAWS functions must therefore be identified in order to perform the tradeoffs. Structured Requirements Specification is an organized method by which to identify functional requirements.

The centerpiece of the method is the requirements model. Appendix B is the IVSAWS requirements model. The model can be divided into two basic components, the process model and the control model. The process model breaks a system into its component functions, shows the data flows into and out of the functions, and describes how the functions operate on the data flow inputs in order to generate the data flow outputs. Likewise, the control model shows the component functions and the control flows into and out of the functions. The basic distinction between the process model and the control model is that the process model describes how the component functions work and the control model describes when the component functions work.

Figure 2.2-l shows the requirements model structure. The data flow diagram (DFD) is used to represent the process model (see DFD #l , Appendix B). The data flow diagram contains processes, data flows and data stores. In the IVSAWS process model, processes are depicted as rectangles with rounded comers, data flows are represented by solid lines with arrows at the end, and data stores are shown as open-ended rectangles. Data flows represent information, in ant form, ranging in complexity from a single bit of information to a complete description of the universe. Data flows can split or merge. Whether merging or splitting, information is always conserved, new information does not appear as the result of a merger and no information is lost as the result a split. Data stores are merely data flows which remain constant when the input data source vanishes. Data stores retain their value until replaced by new data arriving at the store,

Process Model

The process model has a parent-children structure. That is, a parent process appearing on a data flow diagram is defined by another data flow diagram, itself composed of “child” processes, data flows, and data stores. For example, process 1.1 (Configure Warning Zone) on DFD # 1 is defined by DFD # 1.1. DFD #l . 1 has four child processes, 1.1.1 through 1.1.4. The child processes and data flows do not introduce new functions or information into the system; they only describe the system in more detail. Thus, all inputs to a parent data flow must be used by the child processes. In DFD # 1.1, data flows originating from a circle (i.e., “connector”) without a number inside represent data flows which are inputs to the parent process. Conversely, data flows terminating into a blank circle are outputs of the parent process. Circles with numbers inside of them are data flow connectors between child processes on the same data flow diagram. They are used only to improve the readability of the DFD.

The child processes themselves have children and the parentchildren decomposition continues until a process is compact enough to be defined precisely and briefly in a process specification (PSPEC). The process specification describes, in text or through the use of formulas, how the outputs are generated from the inputs.

Control Model

The control model uses the process model as its basis. For each DFD there is one control flow diagram (CFD). However, if a process is completely data driven, its CFD is usually omitted from the specification. The CFDs map control flows between the same processes that are shown in the corresponding DFD. The control flows are shown as dashed lines on the CFD. Unlike a process

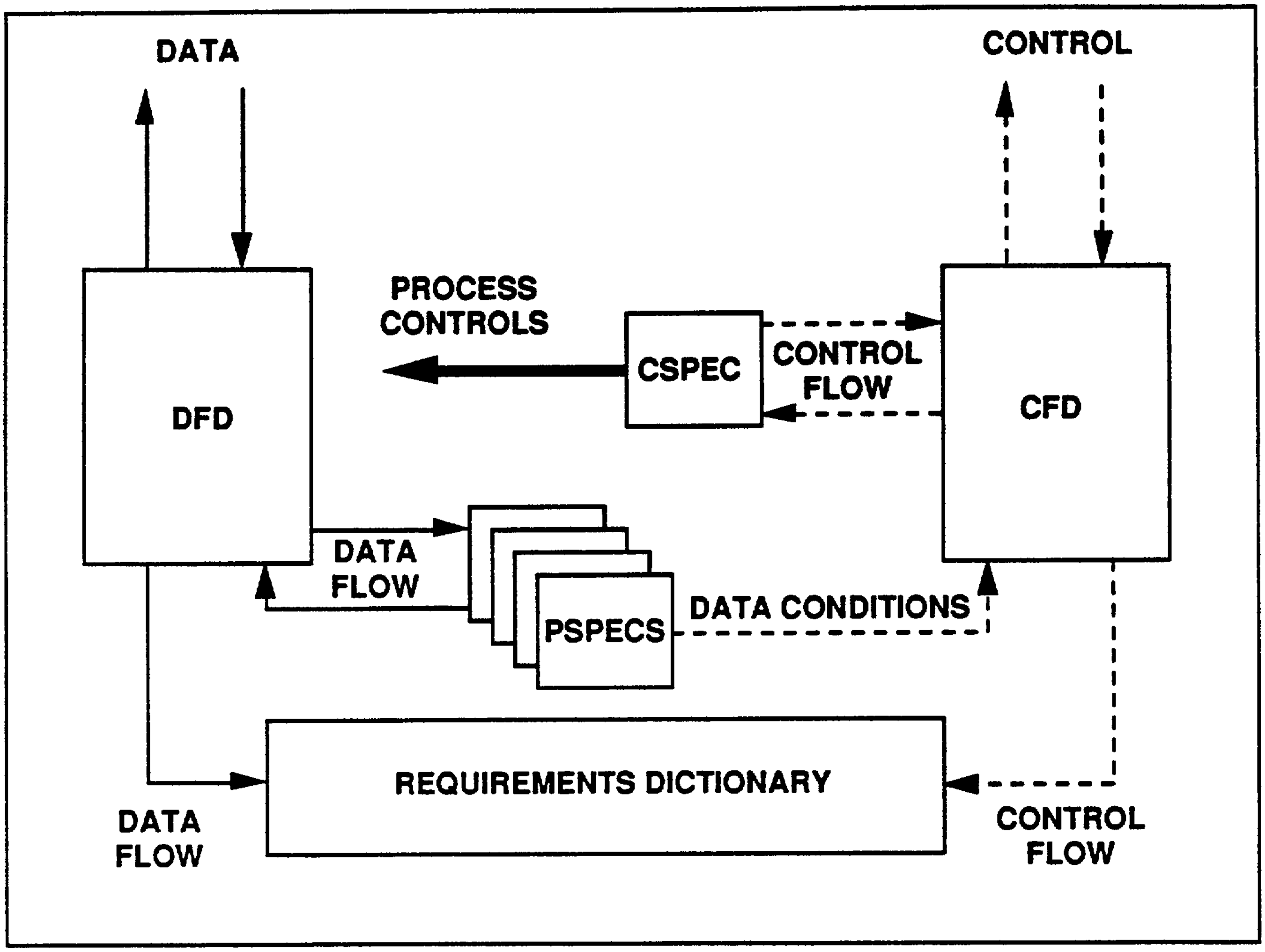


Figure 2.2-1. Requirements model structure.[2]

model's PSPEC(s), the control specifications (CSPECS) originate in between the processes at CSPEC interfaces indicated by a bar symbol on the CFD (see CFD #1, Appendix B).

The CSPEC specifies control processing for the processes on the DFD. The inputs to the CSPEC are control flows. Special control flow inputs called data conditions are generated inside PSPECS; they appear on the CFD, not the DFD. The primary outputs of CFDs are process controls. Process controls enable and disable DFD processes. Thus, the CSPEC specifies under what conditions a DFD process is to operate or be disabled. Process controls are not usually shown on the CFD or DFD. CSPECS may also output control flows which are used as inputs to CSPECs at a parent or child level. There is, however, only one CSPEC per CFD.

Requirements Dictionary

The requirements dictionary, or data dictionary, completes the requirements model structure. It contains an entry for each and every control flow and data flow identifier, along with its definition.

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[2]Hatley, Derek J. and Pirbhai, Imtiaz A., Strategies for Real-Time System Specification, Dorset House Publishing Company, New York, NY, 1988, p.18

3. FUNCTIONAL DEFINITION

The definition of a function includes 1) a statement of what the function does and 2) how well the function must be performed (i.e., functional requirement). Functional definition can be performed at different levels of abstraction. The levels tend to be nested, with a functional definition at one layer encapsulating several definitions from a lower-level layer. IVSAWS levels of abstraction can range from system-level definition to component-level definition (e.g., the function to be performed by a resistor or line of code). Figure 3-1 illustrates the concept of nested levels of abstraction. At present, the scope of IVSAWS functional definition includes only the system and subsystem layers.

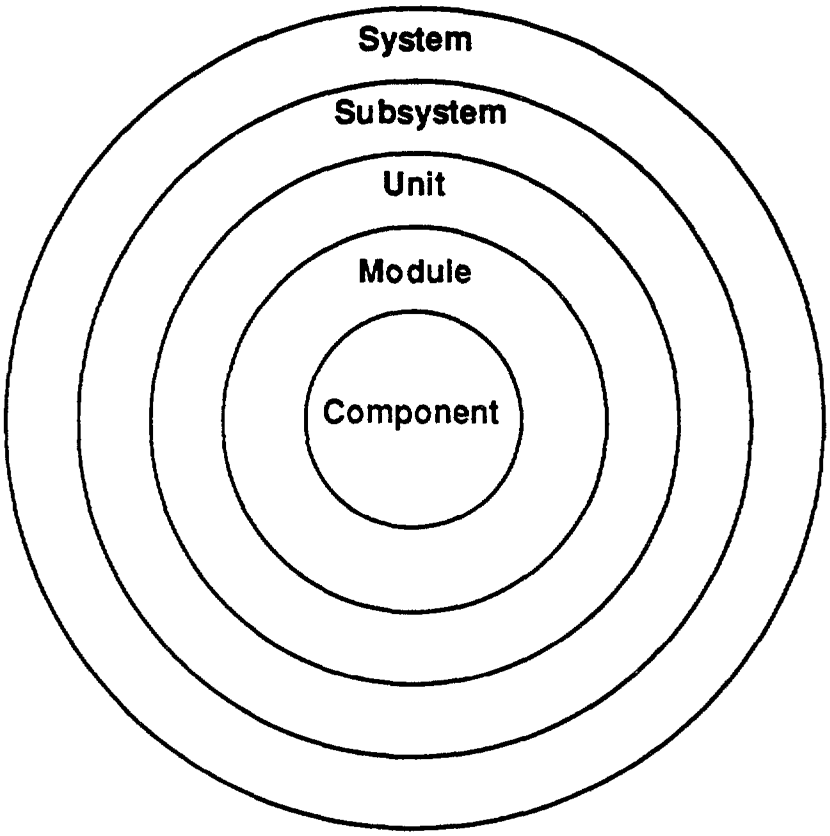
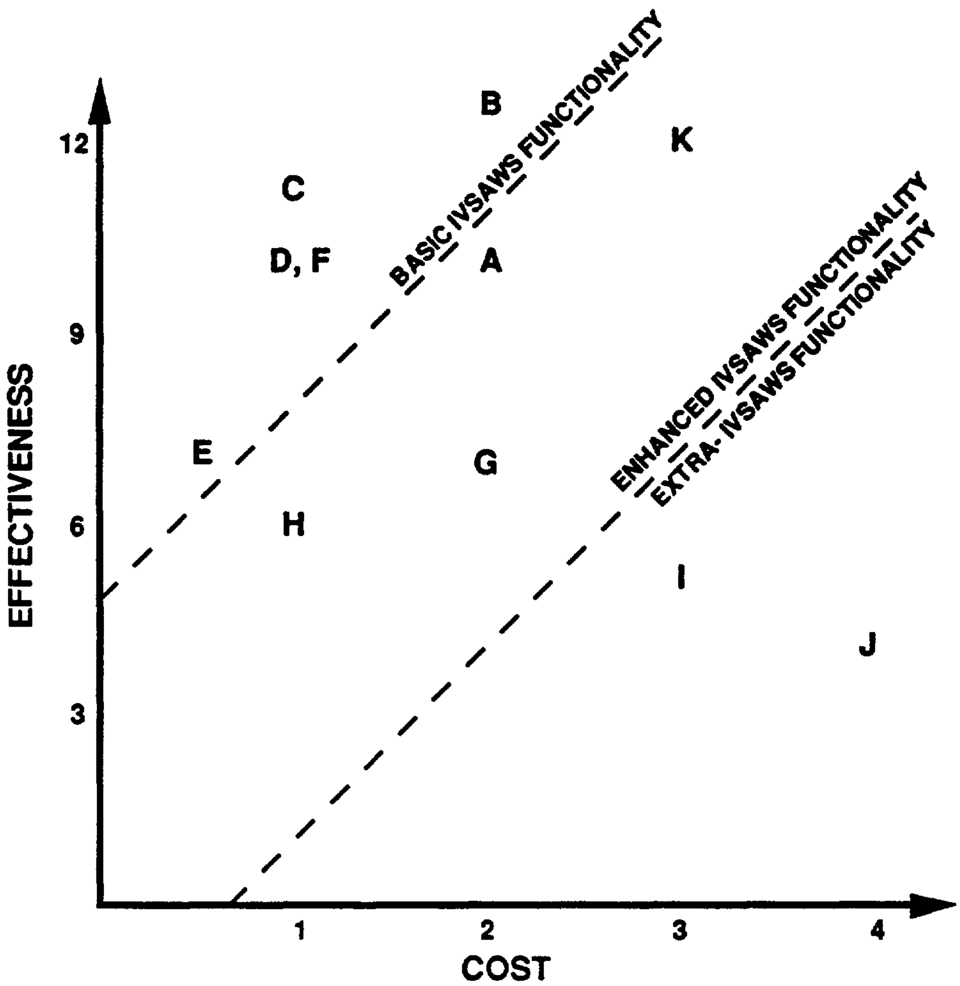


Figure 3-1. Nested layers of functional definition.

Within each layer, several cost-functionality boundaries may exist. That is, functions can grouped such that removal of a single function from the group does not significantly impact the price or effectiveness of the product as a whole (provided, of course, there is more than one function in the group). Figure 3-2 illustrates that, at the system level, two IVSAWS cost-functionality boundaries exist.

The first boundary separates "basic" system functionality from "enhanced" system functionality, Basic system functionality identifies the set of roadway scenarios for which IVSAWS can provide coverage at a cost which is "low" with respect to the effectiveness of IVSAWS application. Effectiveness is measured in terms of scenario frequency, severity, and the judged value of IVSAWS towards reducing accidents in each scenario. Enhanced functionality identifies the set of roadway scenarios for which the value of IVSAWS application (again, measured in terms of cost and effectiveness) is questionable.



SYSTEM FUNCTION (APPLICATION): "NOTIFY DRIVER OF ..."

A = Moving emergency vehicle
B = Train at/approaching crossing
C = Environment-related hazard (e.g., fog, snow, flood, rock slide)
D = Roadway construction zone
E = Infrastructure hazard
F = Accident site (remote activation)
G = School bus or special vehicle
H = Detour advisory
I = Disabled vehicle at roadside
J = Traffic backup (end of queue detection)
K = Accident site (automatic activation)

Figure 3-2 IVSAWS system-level function cost-effectiveness boundaries.

The second boundary separates "enhanced" system functionality from "extra" system functionality. Extra-IVSAWS functionality identifies the set of roadway scenarios for which the application of IVSAWS is not recommended.

In Figure 3-2, the cost factor could assume one of five values as described below:

1. Application requires a transmitter (cost factor = .5)
2. Application requires (1) and a geolocation subsystem (cost factor = 1)

3. Application requires (2) and adaptive area of coverage (AOC) control (cost factor = 2)

4. Application requires (2), but transmitters must be installed in private vehicles (cost factor = 3)

5. Application requires (3). (4), and vehicle probes (data network software) (cost factor = 4).

The effectiveness factor was determined using the combined results the Task B report (IVSAWS application analysis) and the IVSAWS Concept Workshop. The most significant Task B application was given eight points, the least significant one point. The Task B points were then summed with points awarded based upon the expected benefit of XVSAWS application in the rural and urban driving environments (see IVSAWS Concept Workshop report). A "low" expected benefit was awarded one point; a 'moderate" expected benefit was awarded two points, and a "high" expected benefit was awarded three points. Thus, a maximum of six "workshop" points could be achieved. The effectiveness factors are therefore skewed towards the Task B results (1.33: 1 weight relative to workshop results). This was deemed appropriate since the Task B results were derived, in part, from statistical information (databases) whereas the workshop results were based solely on panel discussions.

3.1 IVSAWS Functionality

This subsection defines the IVSAWS subsystem-level functions required to support IVSAWS applications A through H (see Figure 3-2). The functions are a product of the QFD tables and requirements model (Appendices A and B, respectively) developed in support of this Functional Definition subtask. For definitions of the functional inputs and outputs, and to understand how the functions interact, refer to Appendix B.

3.1.1 Secure FCC or NTIA frequency allocation

This function is transparent to normal system operation. However, frequency allocation is the <u>number one</u> IVSAWS system design issue. Without a frequency allocation, there will be no IVSAWS. Based upon a preliminary search for frequency bands in which an allocation is most probable, the FHWA should be in <u>fervent</u> pursuit of at least one of the 220-222 MHz band channels that are reserved for Government use on a nationwide basis.

3.1.2 Define area of coverage (AOC)

Requirement: AOC definition has sufficient precision to limit alert dissemination to one of two parallel roads spaced 30 meters apart (edge-to-edge). AOC definition has sufficient precision to limit alert dissemination to one of two roads intersecting at angles ranging from 30 to 90 degrees.

Inputs: AOC, Data-Quality, Zone-Type, Refined-Zone-Location, Standards

Process: This function conditions a description of the desired area of warning zone coverage into a format which is universally understood by the in-vehicle processes which receive and decode IVSAWS alerts, as defined by IVSAWS standards. IVSAWS deployment personnel (IDP) may provide an AOC in standard format (e.g., a set of coordinates) in which case no conditioning will be required. Data-Quality will then be STANDARD. Conversely, the AOC may be in a non-compatible format (Data-Quality is NONSTANDARD) such as the name of a highway to be covered by a warning zone. In this case the conditioning process will need to be applied.

If Data-Quality is NONSTANDARD, a description of the hazard or advisory situation (Zone-Type) may be required to appropriately condition the AOC.

Outputs: AOC-Coordinates, AOC-Shape

The format of AOC-Coordinates is dependent upon the eventual implementation of the functional requirements. AOC-Shape may be used to reduce the number of AOC,Coordinates needed to define the area of warning zone coverage.

Notes: Based upon the QFD study, "Define AOC" is the most important IVSAWS function. It has the largest impact on product reliability. It is more strongly correlated with customer demands and IVSAWS quality characteristics than any other function. The subsystem which implements this function therefore deserves a significant portion (35% based upon QFD) of the total funds allocated for IVSAWS infrastructure expenditures.

3.1.3 Refine Zone Location

Requirement: RMS error of Refined-Zone-Location shall be less than 30 meters (relative to actual position of hazard or advisory location).

Inputs: Zone-Location, Data-Quality, Standards

Process: This function conditions a description of the hazard or advisory location into a format which is universally understood by the in-vehicle processes which receive and decode IVSAWS alerts, as defined by IVSAWS standards. IVSAWS deployment personnel (IDP) may provide a Zone-Location in standard format (e.g., a set of coordinates) in which case no conditioning will be required. Data-Quality will then be STANDARD. Conversely, the AOC may be in a non-compatible format (Data-Quality is NONSTANDARD) such as a highway designator (e.g. Lnterstate 40) and mile marker number. ln this case the conditioning process will be applied.

Outputs: Refined-Zone-Location

The format of Refined_Zone_Location is dependent upon the eventual implementation of the functional requirements.

3.1.4 Tailor IVSAWS Message

Requirement: Generate outputs in accordance with IVSAWS standards.

Inputs: Data-Quality, IDP-Community-Segment, IDP-Zone-ID, IVSAWS-Message, Standards, System-Time, Zone-Type

Process: Primarily, this function conditions a description of the hazard or advisory situation into a format which is compatible with the IVSAWS message structure, as defined by IVSAWS standards. The message structure will likely be in the form of a message designator followed by a short free text field The message designator could be used as a pointer to a "canned" message or icon which drivers quickly learn to correlate with a specific class of roadway hazard or advisory conditions (see Task E report). The free text field could supplement this data with site-specific information. IVSAWS deployment personnel (IDP) may provide an lVSAWS_Message in standard format in which case no conditioning will be required Data-Quality will then be STANDARD. Conversely, the IVSAWS-Message may be in a noncompatible format (Data-Quality is NONSTANDARD) such as a lengthy description of the types and number of vehicles involved in an accident. In this case the conditioning process will be applied.

Outputs: Alert-Expiration-Time, AlertJD, Alert_priority, Alert-Status, Alert-Type, Standardized-Zone-Type, Tailored_IVSAWS_Message, Zone-ID

3.1.5 Generate Alert

Requirement: Provide warning and advisory zone coverage to all major and secondary roads in the United States.

Inputs: AOC-Coordinates, Alert_Expiration_Time, Alert-ID, Alert-List, Alert_Priority, Alert-Status, Alert-Type, Refined-Zone-Location, Standardardized_Zone_Type System-Time, Tailored_IVSAWS_Message, Zone_ID

Process: This is the "transmit" function. This function compiles the inputs into a set of alerts which are repeatedly disseminated to IVSAWS-equipped vehicles.

Outputs: Alert, Alert-List

3.1.6 Alert Driver

Requirement: When an IVSAWS-equipped vehicle penetrates an IVSAWS zone (as defined by AOC-Coordinates and AOC-Shape), the probability of alerting drivers when the vehicle is at the Driver-Alert-Distance (+/- 1 second) shall be 0.99, whether or not in-vehicle processes correctly receive and decode the corresponding alert. For the purpose of requirement verification, an alert may consist of a flashing light, signal on a test line, or other discrete and measurable event.

The false alarm rate shall be less than or equal to 1 per month. False alarms include the following: 1) alerting a driver when the vehicle is outside the area of intended coverage (as defined by AOC-Coordinates and AOC-Shape), 2) alerts generated due to noise being interpreted as a valid alert, and 3) alerting a driver when the warning or advisory has been suppressed by driver command.

Inputs: Alert, Vehicle-Type, DAWS-Status, Alert_Array

Process: This is the "receive" function. This function compiles received alerts into an array and presents alerts to the driver at the proper vehicle-hazard separation (Driver Alert Distance).

Outputs: Driver-Alert

Note: Based upon the results of Task E, the optimum alert is comprised of the simultaneous presentation of an audio tone and hazard/advisory pictogram followed by a short voice message and generation of a video text message describing the situation. Based upon the IVSAWS Market investigation, drivers would also like to know the distance to the hazard and sa a map with the vehicle and hazard locations displayed. This functionality is beyond the $450 "not-to-exceed" price threshold desired by drivers if IVSAWS is sold as a stand-alone system. However, this functionality can be integrated into a driver-car interface which supports other driver information, safety, navigation and control systems, thereby amortizing the interface cost over a larger set of desired features and systems.

3.1.7 Process Driver Commands

Requirement: Process driver commands as specified in the IVSAWS standards.

Inputs: Driver-Commands, DAWS-Status, Alert-Array Outputs: DAWS_Status, Alert_Array

Process: This function tailors the presentation of alerts to drivers, based upon driver input. A driver may repeat and filter alerts by exercising this function. The commands available to drivers are dependent upon the implementation of the Driver Alert Warning Subsystem (DAWS) which is beyond the scope of this NSAWS contract. At a minimum, five driver commands should be supported: Repeat, Mode, Select, Next, and Previous.

3.1.8 Maintain Standards

Requirement: Periodically update IVSAWS standards based upon feedback from drivers and IVSAWS deployment personnel.

Inputs: Standards, feedback from drivers and IVSAWS deployment personnel.

Process: This is a system maintenance function. The FHWA will need to periodically revise NSAWS standards in order to meet customer (drivers and deployment personnel) demands.

outputs: standards

4. REFERENCES

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6. Highes Aircraft Company, Assessment of IVSAWS Deployment Practicality, Contract DTFH61-90-C-00030, 1993.

7. University of Michigan Transportation Research Institute, Task B Final Report, Contract DTFH61-90-C-00030, 1991.

APPENDIX A

IVSAWS
Quality Function Deployment
Charts

APPENDIX B

IVSAWS Requirements Model

APPENDIX O:
IVSAWS SYSTEM ARCHITECTURE ANALYSIS

This appendix includes an analysis of existing communication and geolocation architectures available to IVSAWS with respect to the IVSAWS functional requirements. Tradeoffs between cost and functionality are identified.

1.0 Introduction

The purpose of this report is to identify the possible communication and position architectures available to the in-vehicle safety advisory and warning system (IVSAWS). The architectures that have been identified vary in technological complexity and cost. Each of the architectures will be evaluated against the requirements for the IVSAWS. Finally, an architecture which is far superior to all of the others will be singled out if it exists.

2.0 Communication Architectures

The available communication architectures provide several throughput options, from one-way data up to two-way voice and data. The throughput options are limited in that no frequency is available for continuous coverage throughout the United States. Some architectures like LPHAR, HAR and AHAR are for remote site transmission only, they require a communication backbone to transport data out to them from the IOC. Technologies like Iridium and Cellular provide for IDP to IOC position transmissions along with voice, however, the cost of transmitting data to the vehicles via these technologies would be recurring and might prove unacceptable to most drivers. Therefore, a combination of technologies could ultimately provide the best offering, as far as cost and data transmission, for the IVSAWS system.

2.1 Local Broadcast

Local broadcast technology provide broadcasting of IVSAWS information directly from a remote site, or possibly from the moving emergency vehicle. The draw of the standard Highway advisory radio (HAR) is that the system is inexpensive, and most drivers have an AM receiver in their vehicle so there will be less cost incurred by the driver for the IVSAWS technology. Low Power HAR provides an added benefit in that no frequency licensing or leasing fees is required. Limitations on the standard HAR and LPHAR is that they are limited to voice transmissions only. The Automatic HAR (AHAR), though the vehicle would have to be equipped with a new RF receiver, has the ability to transmit limited digital data to the vehicle.

2.1.1 HAR/LPHAR

System Description

Low power AM radio stations are regulated by the Federal Communications Commission (FCC) under part 90.242 of their Rules and Regulations. The regulations refer to a 10 Watt AM station, licensed to a governmental agency, used primarily to provide information to motorists. The 10 Watt transmitters are generally referred to as Highway Advisory Radios (HAR). Their Low Power counterpart (LPHAR) are regulated under FCC part 15.113. The low power allows the user to transmit, at no more than 100 mWatts, on a non-interfering basis, without obtaining an FCC license. Licensing is required for HAR radios.

The HAR and LPHAR systems, being limited to 3.5 kHz of bandwidth, is not suited for digital broadcasting. The limitation of bandwidth prohibits the attaching of any sort of digital data to be used for position and direction information, therefore, to alert the driver some sort of a beacon or flashing light is required at the front of the warning zone to indicate that there is a message being transmitted. The HAR/LPHAR transmit zone is limited by the power of the transmitter. When a vehicle enters a transmission zone, and a message is being transmitted, the message will be received when the motorist tunes the vehicles radio to the AM frequency matching that which is being transmitted.

Frequency

The frequency range for the LPHAR transmitters is the AM frequency spectrum, from 530 - 1700 kHz in 10 kHz increments.

Data Rate

Travelers Information Station (TIS) or Highway Advisory Radio (HAR) transmitters are limited to an audio frequency of 3.5 kHz. The limitation

was put into place to prevent TIS stations from playing music and possibly taking away listeners from a commercially licensed station.

Coverage

The range of an LPHAR is greatly affected by the output power of the transmitter. For the unlicensed LPHAR transmitters the coverage ranges up to 0.5 miles.

The range for the HAR radios, with up to 10 watts of output power, the coverage is slightly better than for the LPHARs. For rural areas (rolling terrain) the coverage ranges from three to five miles. In flat rural areas the coverage ranges from six to eight miles. In mountainous and urban areas the range may drop down to one to two miles. Coverage range for each site varies.

Status

The technology is an established technology, utilizing standard AM transmissions. The limitations come in the transmission range. LPHAR technology is one-way and best suited for voice transmissions from a fixed field site along side the roadway to be received by passing vehicles. For mobile usage the limited coverage is a plus but there is not enough bandwidth to send out directional information so the recipients will be all within the range of the transmission. Grounding within the vehicle is another possible limitation for the mobile usage, the better the grounding the better the transmission.

Cost

Costs will be incurred primarily by the IVSAWS application system providers. Since the end user only needs an AM receiver within the vehicle, and most vehicle have an AM receiver within the vehicle it is considered a non-cost incurred item. The transmitter costs range from roughly $850.00 for the basic LPHAR field transmitter and antenna to $2K - $5K for the HAR field transmitter with antenna (note: some HAR companies include the price of putting together the license application package as part of the HAR costs). There will also be costs incurred for the beacon/flashing sign and the means of getting the information out to the field site from the IOC (microwave, spread spectrum, cable, leased lines, etc.) all with varying costs.

System Interfaces

The HAR radios generally come with tape recorder input ports, microphone input ports, RJ-11 jacks for remote phone connections, headset output ports. Most radios can run off of AC or 12 VDC power sources.

Diagram

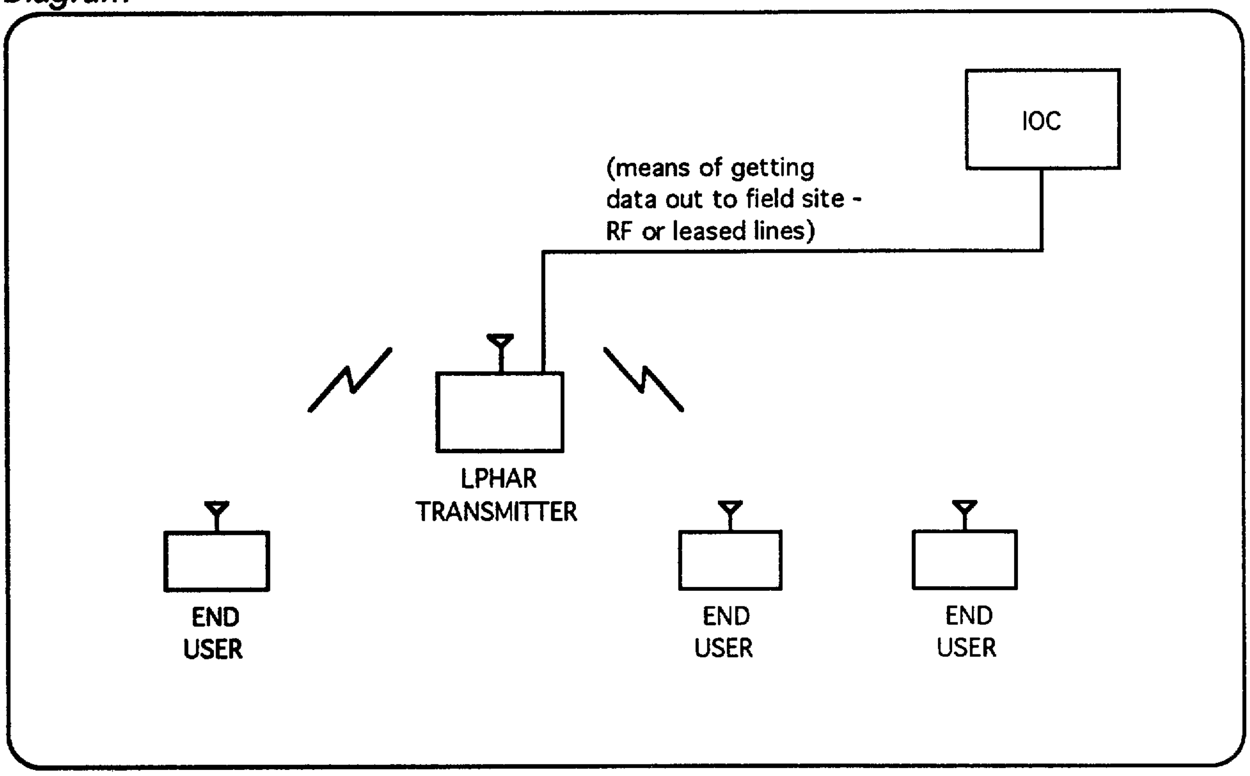

Figure 2.1.1-1 LPHAR Block Diagram

2.1.2 AHAR

System Description

Automatic Highway Advisory Radio is a mobile communication technology that utilizes a licensed radio frequency from any number of transmitter types (e.g. narrow band radios, trunk radios, and shared channel radios) to transmit data to a vehicle for automatic playback.

The end-user can receive messages in one of two ways, with an enabling beacon, or through tones transmitted in front of a message. For the first situation an enabling transmitter is placed in front of the message zone, similar to that set up for the LPHAR/HAR, the enable transmitter, when a message is needed to be received by end-users, will send out continuously an encoded signal (DTMF). The end-users vehicle is equipped with a receiver that scans until it receives an enabling code from the field transmitter. Once the vehicle receiver stops scanning it waits for the message. The message is received after the vehicle enters the message receive zone. The width of the zone has been suggested to be approximately 1.5 miles (distance required for a vehicle driving at 60 mph to receive a 30 second message twice) to 3 miles (distance required for a vehicle driving at 60 mph to receive a 60 second message twice) transmits continuously and enable code.

When a vehicle enters a transmission zone, and a message is being transmitted, the message will automatically interrupt the radios playback selections, i.e. the radio station or the cassette tape, and play the message to the motorist.

It should be noted that the automatic intelligence comes from the IVSAWS Warning unit. The intelligence is the filtering, passing through to the end-user, and storing of messages received.

Frequency

Since AHAR is not a RF technology, but a concept of automatically providing information to the driver, there is no "AHAR" frequency. As mentioned in the system description the RF backbone can be selected from any number of transmitter types. In the past Land/Mobile radio frequencies have been utilized (29.7 to 50 MHz, 66 to 88 MHz, 150 to 174 MHz, 403 to 512 MHz, 806 to 870 MHz and the 900 MHz series).

Data Rate

The data rates vary depending on the RF technology selected. If audio is to be transmitted from the AHAR transmitters to the end-user then up to 7.5 kHz is acceptable. If tones are sent, representing data, then the maximum data rate would be 9600 bps.

Coverage

Coverage for the particular message zone is best limited to the 1.5 to 3.0 miles depending upon the estimated length of the message (30 to 60 seconds). The data will need to be transported from IOC to the remote sites, either via leased lines or some addressable RF technology (spread-spectrum, trunking radios, cellular, etc.).

Status

AHAR technology is one-way and best suited for voice transmissions from a field site along side the roadway to be received by passing vehicles. The technology could also apply to mobile to mobile applications with the transmitting vehicle sending out the enabling signal in the header of the message.

Cost

Costs will vary depending on the RF system chosen, costs will be incurred by both IVSAWS and the end-user. The end-user would have to purchase

the receiver, and an adapter (between the radio and the IVSAWS unit) Prices for the radios range from roughly $500 to $1000, the adapters should sell for no more than $75. The IVSAWS provider will have to purchase the field transmitters (radio, antenna, repeater package and power supply) ranging from $1000 to $3000 per site as well as any equipment required at central (costs will vary depending on system setup).

System Interfaces

The System Interfaces will be dictated by the type of receiver selected, an output connection that will allow the baseband audio to be sent to the IVSAWS Warning unit, such as an RCA jack or a standard phone jack (RJ-11), would be appropriate.

Diagram

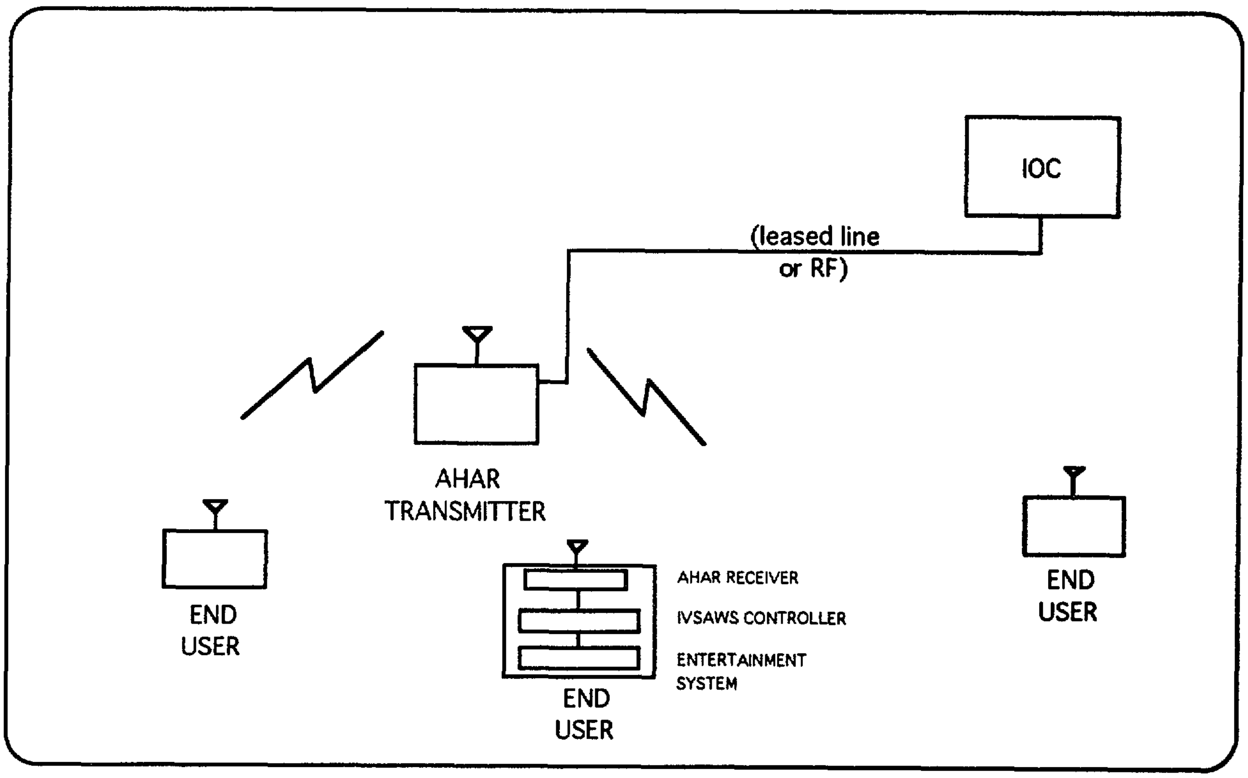

Figure 2.1.2-1 AHAR Block Diagram

2.2 Commercial Subcarriers

Commercial subcarriers, FM (RBDS and SCA) and television (SAP), have a great deal to offer IVSAWS:

- The technology is available now
- Vast coverage area up to 40 mile radius for some radio and TV stations
- Mature technology
- No license required
- No regulations
- Existing facilities (i.e. the radio and TV stations)
- Across the country
- Reliable signals

2.2.1 RBDS

System Description

The Radio Broadcast Data System (RBDS) is a system for co-transmission of digital data and the FM signal. Information is sent from the IOC to the FM radio station which in turn digitally encodes the data and transmits it out on the subcarrier frequency. The transmission is technically robust, due to its narrow bandwidth signal. RBDS is designed to transmit text data to the end-user. Group 2A is dedicated to Radio Text, 2A - up to 64 characters in length, and group 2B with a message length up to 32 characters. The textual data received by the end-user can be easily converted to synthetic speech.

RBDS is best suited for transmitting limited text data, up to 1200 bps but only a few tens are available for discretionary use, to the motorist or message information from the IOC to a remote field site.

RBDS is also well suited for use as an acceptance code, used as a filter,
that is used to make sure that the audio from the SCA transmission is only being forwarded to the driver in a local zone vice a reception wide area, thus localizing the broadcasts. Group 5 provides the transparent data

channels. The channel 2 selection is used as to provide data for the filtering of possible SCA information being transmitted. Messages of any length and format can be sent using the channels within group 5. RBDS receivers continuously scan for group 5 messages even when the end-user is tuned to a non RBDS station. This way when there is an emergency traffic update, the message information can still be received and automatically provided to the end-user.

RBDS can also be used to provide Differential Global Positioning System (DGPS) information to the end-user via the group 3A portion of the transmission.

RBDS can be used as a stand alone system or as a provider of information to the in-vehicle controlling unit, thus allowing for location decisions as to whether or not a message should be forwarded to the end-user.

Frequency

The RBDS is intended for application to FM sound broadcasting transmitters in the range of 87.5 - 108.0 MHz. During stereo broadcasts the subcarrier frequency is to be locked to the third harmonic of the 19 kHz pilot tone, with a tolerance of +/- 6 Hz. During monophonic broadcasts the frequency of the subcarrier is to be 57 kHz +/- 6 Hz.

Data Rates

The data rate is based on the basic clock frequency which is obtained by dividing the transmitted subcarrier freq. by 48, consequently, the basic data rate of the system is 1187.5 bps +/- 0.125 bps.

The baseband coding (data link layer) is structured as follows:

- largest element in the structure is called a group (104 bits each)
- each information word comprises of 16 bits
- each checkword comprises of 10 bits
  used for error protection

- data transmission is fully synchronous and no gaps between groups or blocks

Coverage

RBDS transmission range is limited to the transmission range of the FM station.

Status

The main advantage to RBDS, it is a standard. Car manufactures and radio manufactures are currently manufacturing units that should be available by the second quarter of 1993.

RBDS is best suited for transmitting limited text data to the motorist or message information from the IOC to a remote field site.

Drawbacks to the RBDS idea, include finding a FM station willing to sell IVSAWS sideband time and a reluctance of a station to transmit the transparent data channel information for fear of interrupting their stations entertainment. Another issue is that the cost of sideband usage is not regulated so each radio station will have their own contract that will need to be negotiated. And finally, since RBDS sideband transmission is a potential source of profit for the radio station, there will be much competition for the limited source.

Cost

Depending on the consumer response, an RBDS/AM/FM radio receiver, for the end-user, could cost as little as $50 above the current AM/FM receivers. Costs incurred by the IOC will include, a modem at the IOC ($200 - $500), a phone line to the station (varies per location and type of phone line, a modem at the station, RBDS encoder (around $6000), and the cost of the sideband usage from the station (will vary).

System Interfaces

RBDS receivers could be equipped with RS-232 ports to communicate to the in-vehicle controlling unit. The receivers should also be equipped with an auxiliary port to allow external audio to be piped through (such as using SCA in tandem with the RBDS message).

Diagram

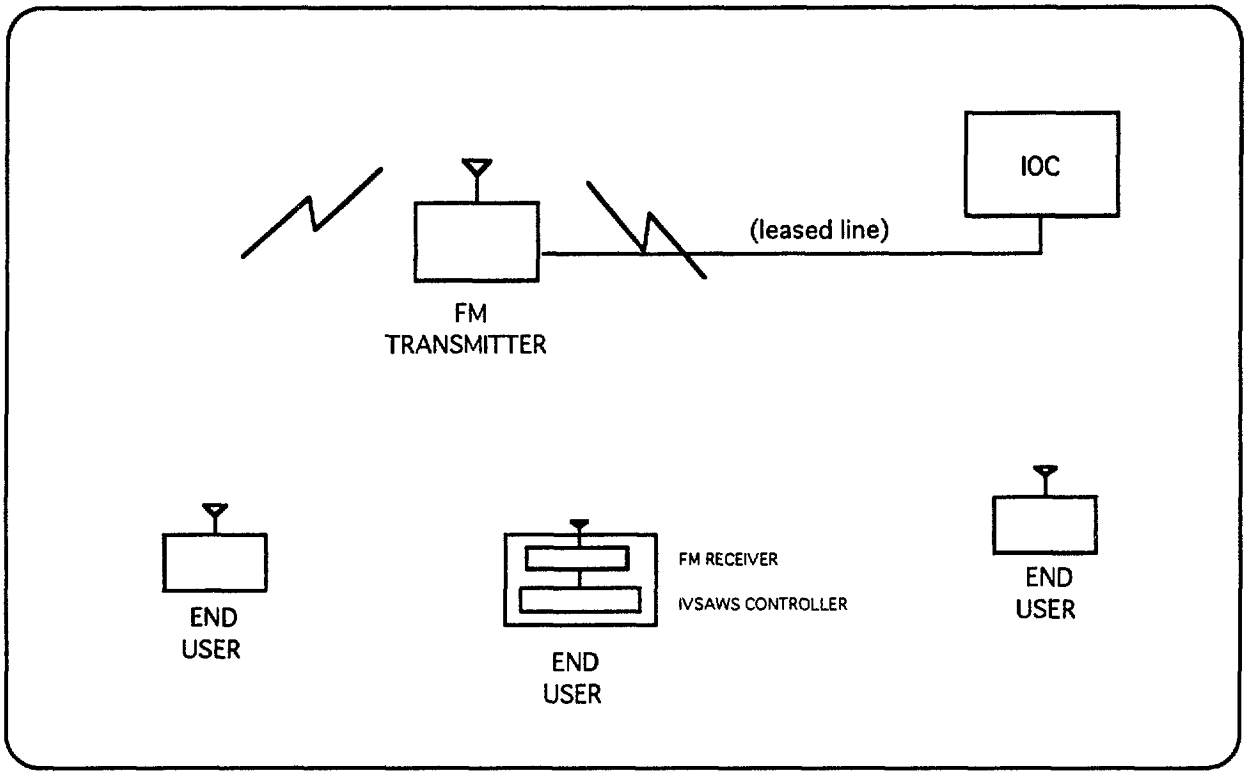

Figure 2.2.1-1 RBDS/SCA Block Diagram

2.2.2 SCA/SCS

System Description

The Subsidiary Communications Authorization (SCA) also known as Subsidiary Communications Service (SCS) is an FM broadcast subcarrier technology that utilizes the subcarrier frequency of 67 kHz, or 92 kHz to transmit data. Because the subcarriers are considered a subsidiary service of the existing broadcast licensee, no further licensing is required. The FM subcarrier is a one-way data transmission, with an audio quality similar to that of an AM broadcast station.

To provide information, digital or audio, to the end-user, the IOC transmits the information, via leased telephone lines, to the FM station with which there is an agreement to utilize their sideband. At the FM station there is a SCA encoder that takes the information sent to it from the IOC and modulate it onto the carrier frequency. Any end-user within the range of the FM stations' transmission will be able to receive the information provided they have a SCA receiver/demodulator.

SCA can be used in tandem with RBDS transmissions that provide a digital header for the audio data (see discussion on RBDS), the header providing digital information such as location codes. SCA can also be used to transmit digital data, thus eliminating a need for another service to transmit the header information, however, messages to the end user would be either in compressed voice or in text format for use in the generation of synthesized voice.

Frequency

There are two FM subcarrier frequencies in common use, 67 and 92 kHz above the main FM channel. An FM subcarrier, restricting the maximum modulating frequency to 5 kHz, has a composite bandwidth of up to 20 kHz.

Data Rates

If using indirect data modulation , the common form is audio frequency shift keying (AFSK), the frequency of the audio tone is varied which in turn modulates the subcarrier. AFSK (the same technology that the dial telephone network used) is cheap to generate the tones and easy to handle but the maximum speed possible is roughly 1200 bps. Direct modulation varies the frequency of the subcarrier, data rates of 4800 are readily attained. There are some estimates out today that unrealistically claim up to 19.2 kbps, achieved if allowed to utilize the whole FM subcarrier spectrum. Changes in the FCC rules and different modulation techniques the 19.2 kbps may possibly be met, however, radio stations are not expected to lease out their FM subcarrier capabilities to one user when they can currently lease to two or more.

Coverage

FM subcarrier transmission range is limited to the transmission range of the FM stations signal. Experience has shown that the wider the required bandwidth of a data FM subcarrier channel, the less robust it is. If a signal includes longitudinally redundancy (redundant across its frequency spectrum in a period shorter than the interval of one transmit bit) then it is more robust for a wider bandwidth.

Status

The FM subcarrier technology is a robust method of transmitting information, and is a very cost effective way to disseminate information over a wide area. The technology is established, services such as MUZAK7, for example, have utilized the broadcast subcarrier technology for years. Problems with multipath and crosstalk can be avoided by the careful selection of encoder and decoder used for the service. Audio FM subcarrier technology has been around for several decades, digital FM subcarrier modulation, however, is a new focus and is in the development stages, transmitting the data at least twice is advised to assure the data is received at the destination unaffected. It is recommend that the Fm subcarrier system, audio or digital, be demonstrated in a working environment, if possible, with all sorts of station formats (classical, rock, etc.) vice a laboratory.

It should be noted, that FM stations sell their sidebands for profit and the cost for the service will vary from market to market.

Cost

There are several costs that will be incurred by the IOC:

Audio	
encoder (at FM station)	- – $4000
Digital	
encoder (at FM station)	- >= $4000
Modem for IOC and FM station	- $200 - $500
Both audio and digital	
Leased phone line from IOC to FM station	- varies
FM station sideband leasing	- varies
Costs incurred by the end-user	
receiver	- $500 - $1300

System Interfaces

Logical Interface
- audio
  - analog voice
- digital
  - RS232/422

Physical connections
- digital
  - 9 or 25 pin connectors
- Audio
  - BNC type connectors

Diagram

See Figure 2.2.1-1.

2.2.3 SAP

System Description

Secondary Audio Programming (SAP) is a TV broadcast subcarrier offering either 46 kHz (stations that transmit in stereo) or 100 kHz (stations that do not transmit stereo) bandwidths. The SAP is a one-way data transmission, and is excellent for analog sound.

Traffic and incident information can be generated at the IOC, sent to the TV station, via phone lines, and modulated onto the TV transmission, where any end-user within the transmission range and with a SAP decoder can receive the information.

SAP can be used in tandem with RBDS transmissions that provide a digital header for the audio data (see discussion on RBDS), the header providing digital information such as location codes. As an alternative, digitized data in the form of 'tones' can be placed in front of the audio messages to convey information such as message type, zone message is for, direction the message is intended for, etc., a tone generator at the IOC and a tone decoder (standard Hays compatible modem) in the vehicle would be required. The DTMF decoder could be part of the IVSAWS Warning Unit.

Frequency

TV stations broadcast the subcarriers on their aural carriers either 46 kHz (stations that transmit in stereo) or 100 kHz (stations that do not transmit stereo) bandwidths.

Data Rates

Data rates can vary up to 19200 bits per second depending on the data circuits used and the amount of bandwidth available for the SAP (monorail stations provide more bandwidth).

Coverage

SAP transmission range is limited to the transmission range of the TV stations signal. TV stations generally have greater antenna heights, better transmitter locations, and more radiated power than FM station.
TV stations use much less audio signal processing than most FM stations.

Status

Currently only a few commercial TV stations user their SAP for any revenue related activity thus providing a rich resource from which to draw from. One also finds that TV stations are not 'packed in' to permit the most number of stations in the same geographical area, therefore less possibility for interference. And as a last note, no portion of the signal is taken away in order to provide frequency for the subcarrier, thus providing for a stronger more consistent signal for the sideband.

Cost

There are several costs that will be incurred by the IOC:

encoder (at TV station)	- – $4500
Leased phone line from IOC to TV station	- varies
TV station sideband leasing	- varies

Costs incurred by the end-user

receiver	- -$200+

System Interfaces

Logical Interface
Analog voice, there may be AFSK used for the header information to the IVSAWS Warning unit (which will require a tone decoder).

Physical connection
The physical connection expected for the SAP receivers are of BNC type.

Diagram

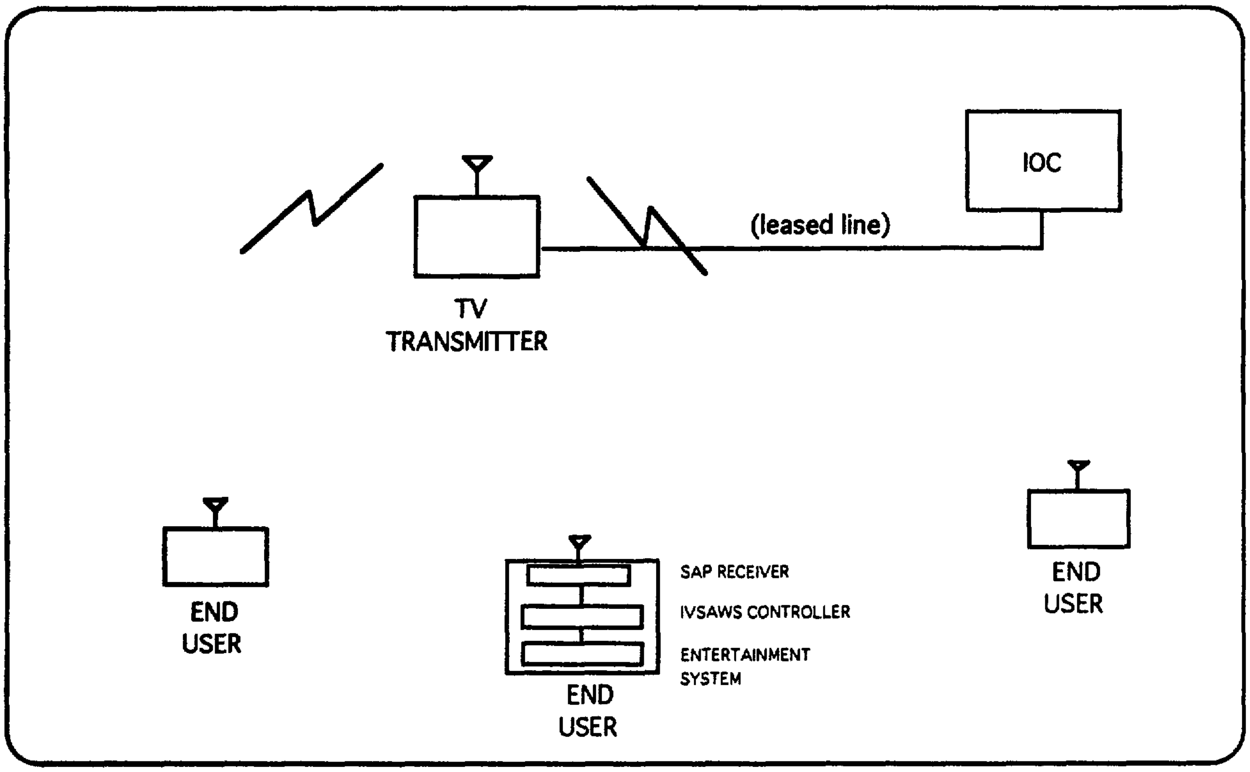

Figure 2.2.3-1 SAP - Data Block Diagram

2.3 Centralized Broadcasts

Centralized broadcasting architectures broadcast from a central location but are not a subcarrier on a primary frequency.

2.3.1 T-NET

System Description

A new wireless communication technology targeted for the frequency range below 900 MHz is a technology identified as T-NET. This system provides bi-directional digital or analog (voice) information transmission. The T-NET system employs previously unusable broadcast frequencies in a manner which will not cause interference to broadcasters. An unused channel adjacent to a broadcasting TV channel is used for transmission but only during the horizontal blanking interval (HBI) and the vertical blanking interval (VBI) of that TV channel The signal appears as a "pseudo sideband" on the host TV signal. Therefore no interference is caused. Compatibility with nearby data links is achieved by sending short, precisely timed pulses (roughly 5 microseconds) of data, much like radar. In the centralized system, a concentric grid is established by means of pulsed transmissions (range gates) and shaped antennas. The pulses are synchronized in the down link with the HBI of the co-located TV transmitter with which it cooperates. The small remote stations respond as they are addressed. Thus the distance to each subscriber may be accurately determined by measuring the transit time of these transmissions. The service area, partitioned into angular sectors, is used to identify the bearing to each end user. The system is compatible with cable or satellite down link delivery systems. The vehicle will need to be supplied with a transponder.

Frequency

The technology can be used for all types of data transmissions through out the radio spectrum. The current target market is the interactive video and data services (IVDS). The FCC is currently planning to award 2 (218 - 219

MHz band) licenses, for IVDS applications, in each of the identified 734 cellular markets by lottery.

Data Rate

The system is capable of providing up to 75,000 simultaneous bi-directional transmission links on one TV channel, each at a data rates to and from each subscriber may range from a low of 10 bps to a high of 16 Kbps.

Coverage

The service area of the T-NET system is defined by the power of the transmitting/receiving equipment at the control broadcast site and is in the range of a 20 to 30 miles radius. The area is also partitioned into angular sectors which are typically 15 degrees wide, at UHF range.

The radio frequency propagation causes numerous technical problems including station mobility, propagation characteristics of the frequency band, natural and man-made interference, reflection, and noise. Ground-based networks encounter the most difficult environment in terms of propagation and RF connectivity. Radio paths over several miles long may suffer from fading, and the longer the path, the more prone to fading the transmission. Fading is usually caused by atmospheric changes and ground and water reflections in the propagation path. The technology is also susceptible to multipath.
(May not want this: which is not good for mobile use, and for this reason it might be considered best for fixed roadside information.)

Status

The system has been under development for several years and tested under FCC experimental licenses in Los Angeles and Salt Lake City by Radio Telecom and Technology, Inc.

Cost

The current estimated cost for the central station is $150,000 - $200,000, with the end user unit running around $125. The cost of the end user unit does not include the cost of the modem adapter card required for the system interface.

System interfaces

The end-user unit can be equipped with an RS-232 interface port. Software would have to be written to provide for the broadcast mode in lieu of the standard point to point handshaking common with RS-232 protocols. The end-user unit provides a DB-9 connector for the RS-232 interface.

Diagram

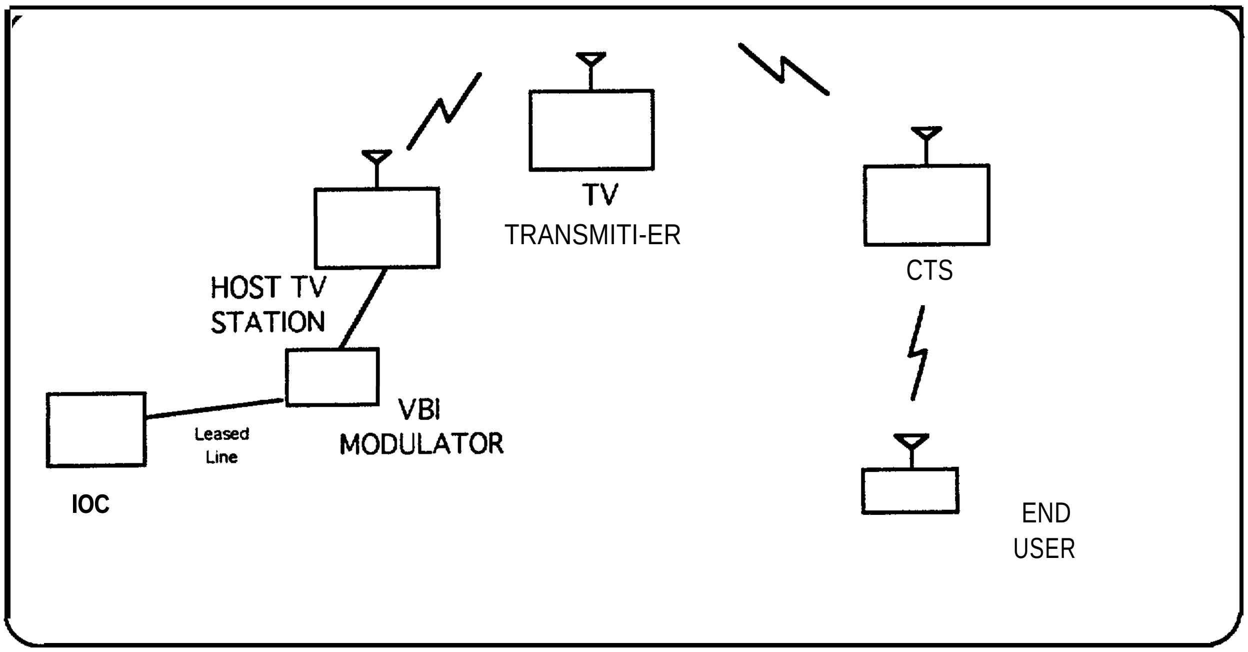

Figure 2.3.1-1 T-NET Block Diagram

2.4 Point-To-Point

Point to point communication architecture's are good for data and voice transmissions between the IOC and the IDP. Point-to-point communications consist of Cellular, Iridium, impulse Radio, and Packet-Data Wide-Area Network Services. The architecture would also be useful in transmitting messages out from the IOC to a remote site. The technology is established, but unfortunately their are recurring costs and many users taking advantage of the systems making for saturated markets in many urban areas.

2.4.1 Cellular Radio

System Description

Cellular radio is a technique for frequency re-use in a large radio communications system. It is mainly known by what is its largest implementation by far, the mobile telephone network. It gets its name from the fact that an area is divided into cells which are 2 to 20 miles in diameter. In the center of each cell, a control radio handles the network management functions including the assignment of frequency sub-channels. A radio requests a frequency over a control channel and one is assigned by the control radio. The cellular layout allows frequencies to be reused in non-adjacent cells.

A second generation of cellular systems is in development and is characterized by digital transmissions and enhanced network control. The new digital cellular system will provide greater bandwidth and frequency re-use capability. Digital cellular systems, in some areas, are planed to be in place by 1996. Cellular radio provides a reliable, low cost solution in those situations where a low rate data or voice grade communications link is required on a part time, or demand basis.

Systems have been demonstrated which utilize a cellular telephone in conjunction with a modem to allow communication between a traffic management center and equipment in the field. In the case of IVSAWS the cellular phone technology could be used to “dial-up” a HAR or LPHAR to update messages. This eliminates the need for a permanent connection to the field device and allows flexibility in installing and moving these devices where needed. Cellular technology provides a good point-to-point means of getting incident information from the field (IVSAWS deployment personnel) to the IOC.

Socrates (System of Cellular RAdio for Traffic Efficiency and Safety), an IVHS application in Europe, utilized the cellular radio technology. The approach was based on the use of a common down link and an single multiple-access uplink in each cell of the cellular radio network - this way cellular radio can provide the high capacity duplex link without unduly loading the radio network.

Frequency

Currently, the frequency assigned for Cellular service transmitters are in the range of 824.04 MHz to 848.97 MHz and the receiver frequency is from 869.04 MHz to 893.97 MHz. A cellular voice channel only requires 5 kHz of bandwidth, but a channel spacing of 30 kHz is used in order to have an acceptable noise level.

Data Rates

Cellular system bandwidth and capacity depends largely on the method of multiple accessing, the distance between relay stations, and the number of users. Analog cellular, with a relatively low capacity (4800 bps), has already reached its limits, and communications quality is suffering degradation. However, to ease this situation and boost capacity, second generation cellular in the form of digital technology such as Time Division Multiple Access (TDMA) has been introduced that conforms to Electronic Industry Association Interim Standard (IS-54), which specifies a channel spacing of 30 kHz and that each digital channel operate at 48.6 Kbps carrying three user signals. TDMA increases cellular transmission capability by three times over analog's capacity and Frequency Division Multiple Access (FDMA) can be used to grow from 165 simultaneous users per cell to 330 users per cell. Therefore, both can further increase system capacity up to six times, under ideal conditions.

Coverage

The cells in cellular coverage are two to twenty miles in diameter, and allow communication between the user's mobile telephone and the centrally located switching system which connects with the regular telephone network. When the caller moves from call to call, the central switch automatically moves the call to the new cell site and a new radio channel. Cellular telephone calls are automatically assigned to one of many available channels from a particular cell site. Area coverage for this technology depends on the radio frequency band used for the transmission of signals. For current frequencies in use for cellular systems, cell sites are located up to 20 miles apart.

Status

Industry experts predict that by 1995, any cellular telephone user will be able to call from almost anywhere in the metropolitan areas of the United States or on any major interstate highway. With its rapid expansion, subscribers are currently signing up at the rate of more than 130,000 per month, this may mean that there may be delays before a cell is available to make any sort of call. The use of cellular telephone services in rural areas may be non existent if there is not a cellular service transmitter in the area.

The Cellular system provides a 99.95% reliability rate provided it is applied within the limits of coverage. Cellular radio links are subject to severe variations in received signal strength due to local variations in terrain, man-made structures, and foliage. Cellular links are easy to maintain because of the modularity of parts which reduces the time required to make changes or repairs. Spare and replacement parts, including new equipment, are readily available as off-the-shelf products. Cellular telephone service is available to any type of user.

Cost

Costs incurred by the IOC:

Cellular phone (one phone at IOC, more may be needed if phones to be used for remote sites)	**- from -$200**
Modem (necessary if trying to send out digital information)	**- from ~$200**
Cellular phone service	**- varies**

End-User

Cellular phone	**- from -$200**
Modem (this may be put into the IVSAWS Warning unit)	**- from ~$200**
Cellular phone service	**- varies**

System Interfaces

Cellular phones may provide an interface to facsimile, modem and a pager/message unit. The interfaces are expected to be commercial standard, coaxial, RS-232 DB-25, or RJ-11. It should be noted that all phones are not created equal so the connections may not be uniform.

Diagram

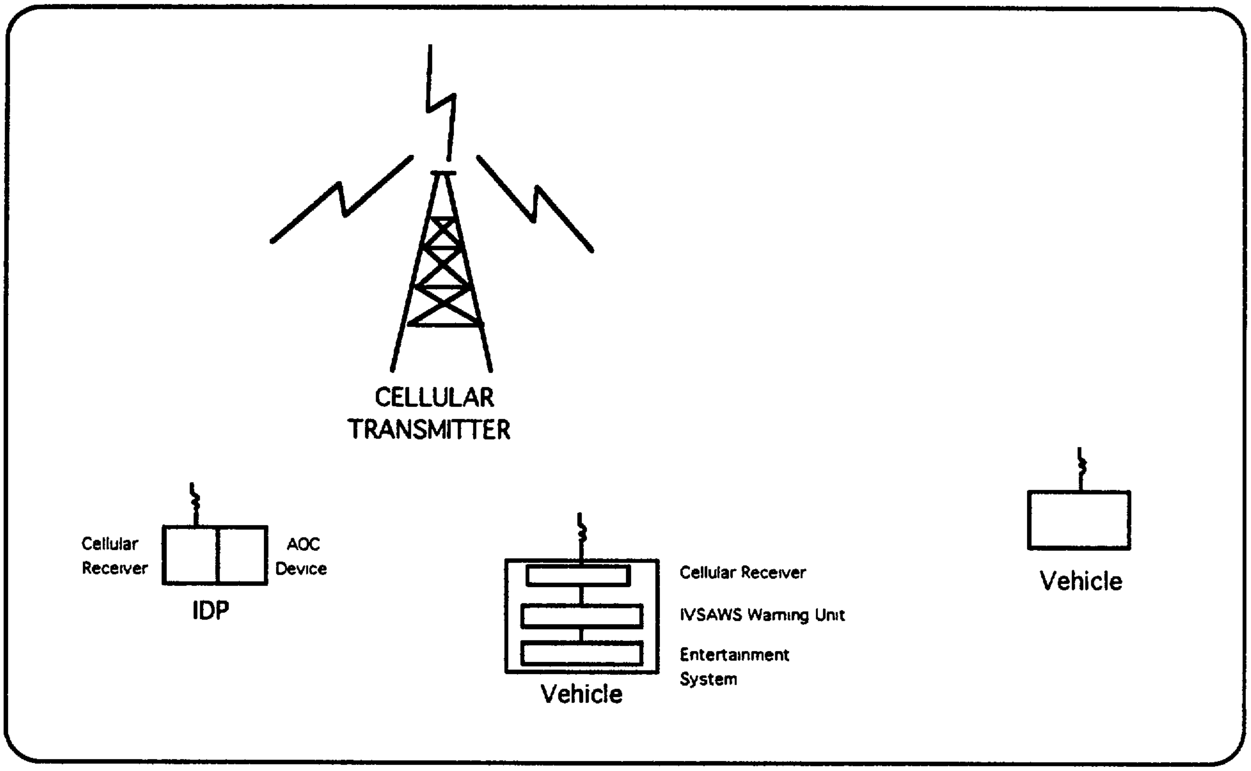

Figure 2.4.1-1 Cellular Block Diagram

2.4.2 Iridium

System Description

Iridium is expected to mark the next major milestone in global communications. The system will employ 66 low earth orbit (LEO) satellites and hand held telephone units. The satellites will communicate with user terminals and gateway stations on the ground, as well as with other satellites in the constellation. The system will provide point-to-point communications from anywhere to anywhere on Earth.

The system combines two wireless communications technologies: space communication systems and cellular telephone systems. This is accomplished using the following technologies: small satellites, phased-array antenna systems, functionally dense radiation-tolerant semiconductors, advanced baseband processing architecture's, and distributed network architecture's.

The Iridium system is expected to be fully operational in 1997. It will support voice communications, radio determination services, facsimile, data transmission and paging for millions of users worldwide. The Iridium technology provides a good point-to-point means of getting incident information from the field (IVSAWS deployment personnel) to the IOC.

Frequency

The Iridium works in the 1.8 - 2.2 GHz radio spectrum which has been licensed by the FCC for LEO satellite communications.

Data Rate

Each cell in the Iridium system is capable of supporting up to 110 simultaneous bi-directional transmission links (assuming 10.5 MHz of spectrum). The system will provide digital voice at 4800 bps and digital

data at 2400 bps. The data transmissions are expected to include geopositioning, facsimile, raw and global paging data.

Coverage

The service area of the Iridium system is defined to be the entire surface of the earth and the space above it. Each cell in the constellation will service a 372 nautical mile diameter area. The Iridium system will provide 110 users per cell which represents half the number of users supported by an individual land based cell.

Status

The consortium was formed in 1991 and is expected to provide funding through 1997. The major system milestones are listed below:

a) 1994 - first 7 satellites launched, system control facility operational, and four gateways operational;
b) 1996 - early Iridium service available and full constellation deployed;
c) 1997 - the Iridium system and additional gateways are operational.

Cost

The Iridium system is a lower density, higher priced service than is cellular telephone. The per minute cost is expected to be 3 - 10 times that of conventional cellular. The current estimated cost for the basic user unit is estimated at $3000 with an expected decrease to $1000 as volume increases due to customer demand. The estimated user cost is $50 per month plus $3.00 per minute for outgoing calls. The estimated cost of the satellites and the ground stations has been estimated at $2.5 billion in 1991 dollars.

System Interfaces

The Iridium user unit is expected to provide an interface to facsimile, modem and a pager/message unit. The interfaces are expected to be commercial standard such that existing equipment is capable of being interfaced to the Iridium user unit.

2.4.3 Impulse Radio

System Description

Pulson Communications has applied for a "Pioneers Preference" from the FCC to implement Impulse radio, which is an ultra wide band communications technology. The actual technology employed is known as pulse position modulation. The system communicates by slightly changing the timing of very short pulses instead of by using AM or FM techniques.

The system uses pulse trains which are generated at intervals between 0.5 and 1.5 nanoseconds (ns). Typically, 1 .O ns and 0.5 ns pulses have center frequencies of 1 gigahertz (GHz) and 2 GHz respectively. The pulse train is modulated by slight differences in time from the expected output. These slight differences are called dithers.

Due to the short nature of the pulse, large amounts of information can be sent in this manor. The system bandwidth is typically 100+ percent of the center frequency and it has a Gaussian distribution. Due to the bandwidth, no processing is necessary to spread the signal's energy. The bandwidth also reduces the chances of interference with other systems operating in the same vicinity.

Frequency

The Impulse radio works in the 1 .O to 2.0 GHz radio spectrum. Initial FCC testing has not found frequency disturbances to existing equipment.

Data Rate

Impulse radio will allow approximately 7000 duplex conversations to take place in a 5 mile radius area. It is also expected that video will be accommodated at real-time video data rates. At short ranges, Impulse radio is capable of providing more than a Gigabit per second of communication capacity.

Coverage

Pulson Communications has applied to use Impulse radio in the Personal Communications Services (PCS) market. Each user will be assigned a unique identification number similar to a phone number. A PN code sequence will then be used to separate user channels, using a 32 bit PN code will allow approximately 4 billion channels. The service area of the Impulse system will be defined in a similar manner as are cellular phone network cells.

Status

Pulson Communications Corporation filed for a Pioneer's Preference in May 1992. The FCC has been studying the application and as of yet has not made a decision. Initial operations are expected to be in the following areas:

- **a) District of Columbia**
- **b) New Jersey**
- **c) Pennsylvania**
- **d) Delaware**
- **e) Maryland**
- **f) Virginia**
- **g) West Virginia**

This area is also serviced by a telephone operating company. This is being done to provide an alternative to the Baby Bell for mobile communications services.

Cost

The Impulse radio system portable terminal is expected to be produced for under $ 200.00. The base systems are expected to be similar in cost to existing cellular base stations. The actual per minute and service charges have not been discussed. It should be considered that the technology may be used and the PCS issue could then be dropped.

System Interfaces

The Impulse radio system portable terminal is not completely defined at this time. The fact that Impulse radio is being considered as a direct competitor to cellular telephone, it can be expected to provide interfaces to all current and future cellular unit external interfaces. The interfaces are expected to be commercial standard such that existing equipment is capable of being interfaced to the Impulse radio system portable terminal.

Diagram

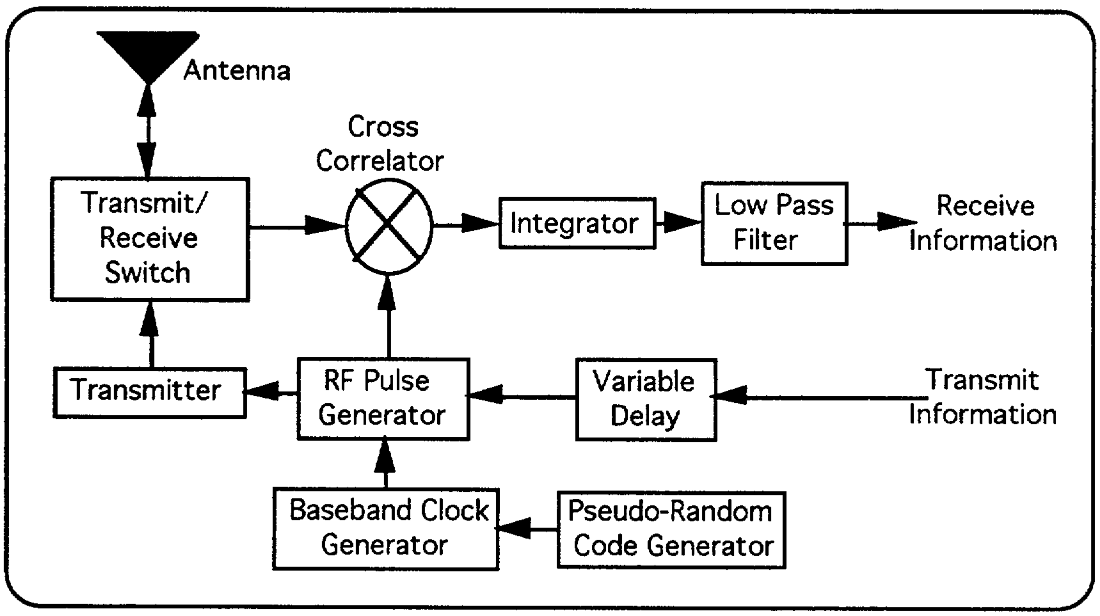

Figure 2.4.3-1 Impulse Block Diagram

2.4.4 Packet-Data Wide-Area Network Services

System Description

Packet-data wide-area network services are provided to mobile users to allow for a two-way transferal of data. The services areas are controlled by third party vendors and the areas are currently limited to urban and suburban markets. Services offered by different providers tend to utilize different protocols thus limiting the product purchased to match the service provided.

Users pay a fee for the service based on the amount of data activity, that is both senders and receivers - just like cellular. The ADVANCE system in Chicago is utilizing the Ardis mobile data network services. TravTek is utilizing the Motorola Data modem for their testbed.

Frequency

Frequency ranges depending on the service area and the provider. System frequency is leased from the provider.

Data Rate

Data rates will vary based on the mobile modem technology utilized for a particular service. Examples of 2 current mobile modems is the Ericsson Mobidem radio handles up to 8 kbps, and the Motorola Radio modem can currently handle 4800 bps with a soon to be available upgrade that will handle up to 19.2 kbps.

Coverage

The range of the networks is measured in miles, however, the range is limited by the amount of transmitter coverage for the area. Currently Ardis has 1200 transmitter sites that are connected to network control points through a leased-line network covering roughly 400 metropolitan areas. RAM mobile data has 800 base stations in operation throughout the US, their stations are interconnected through leased-line networks to a national control center.

Status

The system is limited to urban areas and one system cannot talk to another system.

Cost

IOC

Modem

Ericsson	$1395
Motorola	$3599 - $3999

Subscriber fee	
RAM	**$0.03 - $0.77 per packet**
Ardis	**$0.15 - $0.17 per packet**

End-User	
Modem	
Ericsson	**$1395**
Motorola	**$3599 - $3999**
Subscriber fee	
RAM	**$0.03 -$0.77 per packet**
Ardis	**$0.15 - $0.17 per packet**

System Interfaces

Each modem has its own proprietary packet **switching protocol. The physical interface to a computer is standard RS-232.**

Diagram

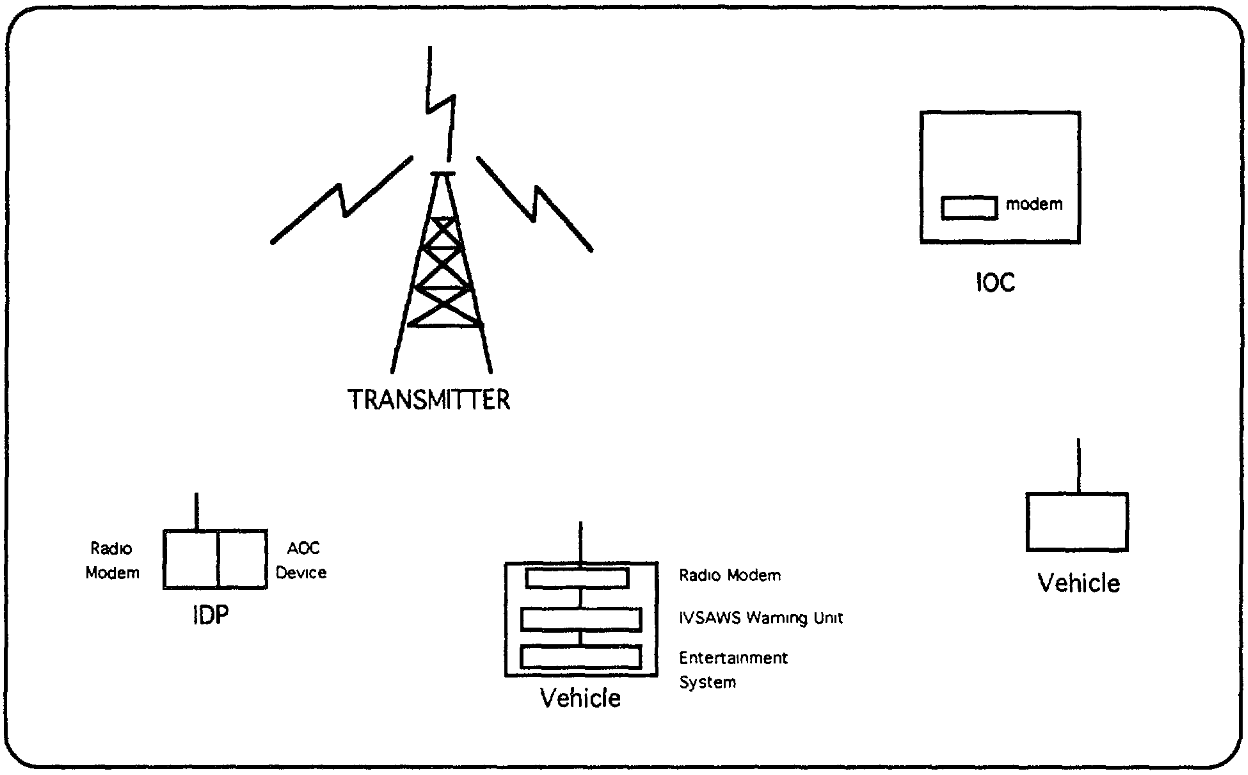

Figure 2.4.4-1 Packet Radio Block Diagram

2.5 Communication Back-Bone (IOC to Remote sites)

The RF options available to provide remote sites with information regarding an incident information are: trunking, shared channel, and microwave. Trunking and shared channel communication technologies, not only could provide data to remote sites, but provide a means for the IDP to send AOC and incident information from a remote site to the IOC.

2.5.1 Trunked Radio System

System Description

The trunked radio system gets its name from the "trunk" line used in commercial telephone communications, which is a communication path between two points. The trunk line is time-shared by several different users. This method of increasing the efficiency of a channeled radio system works by dynamically managing the use of the radio channels.

The main components of a trunked radio system include the Site Equipment (base/repeater station) and User Equipment (mobile/portable units). Therefore, the coverage is the same as a two-way radio.

Trunk radios are well suited for communication backbone configuration bringing IOC data out to remote sites. Used in this way, trunk radios provides greater flexibility as compared to dedicated land lines.

Frequencies

The system operates on the 403 to 512 MHz and 806 to 870 MHz frequency bands and requires FCC licensing prior to usage. Frequencies are assigned for each channel, with each channel requiring a license.

Data Rate

Transmit and receive frequencies can be digitally trunked up to 25 channels with each channel using the standard data rate of 9.6 Kilobits per second (Kbps) on a 25 kHz channel spacing.

Coverage

Coverage for the digitally trunked radio channels depends on the terrain. In a mobile to mobile situation, the coverage could reach up to 10 miles. From the IOC to a mobile receiver the range of coverage could reach up to 20 miles. Coverage between repeater stations could range up to 50 miles.

Status

Ground base stations, must consider the environment in terms of propagation of the signal. Environmental design considerations are: propagation characteristics of the frequency band, natural and man-made obstruction, reflection, and atmospheric noise.

The trunking system is a proven and reliable media for voice and data transmission. It provides better reliability compared to a channeled system. Maintenance of the system does not pose any problem because of the availability of proven spare and replacement parts in the market.

Cost

IOC	
Frequency usage	~$13 per month per radio (depends on area to be covered)
Base/repeater station (includes antennas and other assorted accessories)	-$1200
Mobile Unit	4700

End-user
Cost prohibitive from both a frequency usage standpoint (dollars and end-users on the channel), and unit cost.

System Interfaces

The logical interface for data transmission will most likely be a proprietary protocol. The physical interface connection, for data transmissions, will be of a standard commercial form such as RS-232.

Diagram

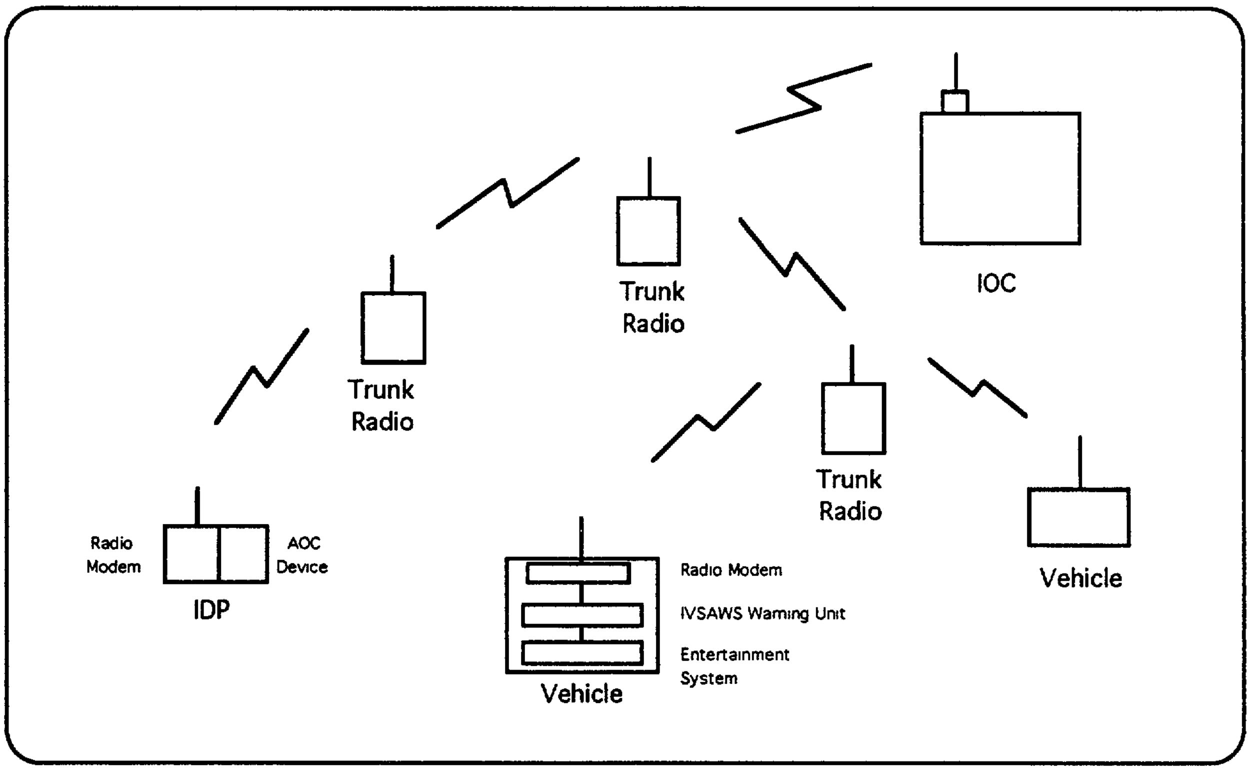

Figure 2.5.1-1 Trunk Radio Block Diagram

2.5.2 Shared Channel

System Description

Shared channel radio is a mobile radio system allowing subscribers to share limited radio channels. These type of radio circuits may be characterized by their carrier frequency, which largely determines the behavior of the path. Application of this technology in the IVSAWS system is for point to point and multi-point voice or data transmission from hubs to the IOC, a communication backbone.

Frequency

Frequencies in the Low Band of 29.7 to 50 MHz, Mid Band of 66 to 88 MHz, High Band 150 to 174 MHz, Ultra High Frequency Band of 403 to 512 MHz, 806 to 870 MHz, and the 900 MHz series are assigned by the FCC to a shared channel system that provides service to various industries for radio communication.

Data Rates

Shared channel capacity depends on the available frequency allocated for specific service by the FCC as listed in the FCC Rules and Regulations, Table of Frequency Allocations Part 2 - Frequency Allocations and Radio Treaty Matters General Rules and Regulations. Channeled radio can range from 1 to 4 channels with different transmit and receive frequencies of up to 128 channels for synthesized microcomputer controlled programming of frequencies.

The line of sight radio links in the range of 1 SO MHz to 900 MHz provide multi-channel transmission capability of 12 to 120 nominal 4-kHz voice channels in a Frequency Division Multiplexing (FDM) configuration.

Coverage

Area coverage for this technology depends on the radio frequency band used for the transmission of signals. Frequencies assigned for the shared channel service fall under the radio link line-of-sight propagation, which is made up of terminal radios and often one or more repeaters. Repeaters are spaced considerably based on the terrain and earth curvature. Coverage can vary in range from up to 20 miles from dispatch to mobile and up to 50 miles for base station to base station.

Status

Ground radio links are subject to severe variations in received signal strength due to local variations in terrain, man-made structures, and foliage. For frequency ranges for shared channel above 30 MHz, radio signals tend to pass through the ionosphere, rather than reflect or refract sufficiently for use far beyond the visible horizon. That is why these frequencies are useful for line of site communication. The major setback **for the radio communication media is the requirement for frequency licensing. System expansion is dependent upon the availability of frequencies.**

Properly designed radio links will provide a reliable media available at least 99.95% of the time. Reliability is measured in terms of the radio frequency bands employed. Radio links are easier to maintain because modularity reduces the time required to make changes or repairs. Spare and replacement parts, including new equipment, are readily available as off-the-shelf products. Service life of the base stations and mobile units have averaged 20 years.

Cost

IOC would require:

Transceiver	**$ 500 - $3000**
Modem	**$1500 - $4000**
Antenna	**$50 - $200**

frequency usage's (licensing or leasing of the frequencies)

Field (IDP or fixed site)

Transceiver	$ 300 - $2000
Modem	$1500 - $4000
Antenna	$ 50 - $200

End-user
cost prohibitive in the frequency and equipment arena's. Recommendation is that this technology be used as a communication backbone to provide a means of getting the data out to remote sites.

System Interfaces

Connection of channeled radio to telephone or telegraph link requires an interface modem. The interfaces are expected to be commercial standard such that existing equipment is capable of being interfaced to the RF user unit.

Diagram

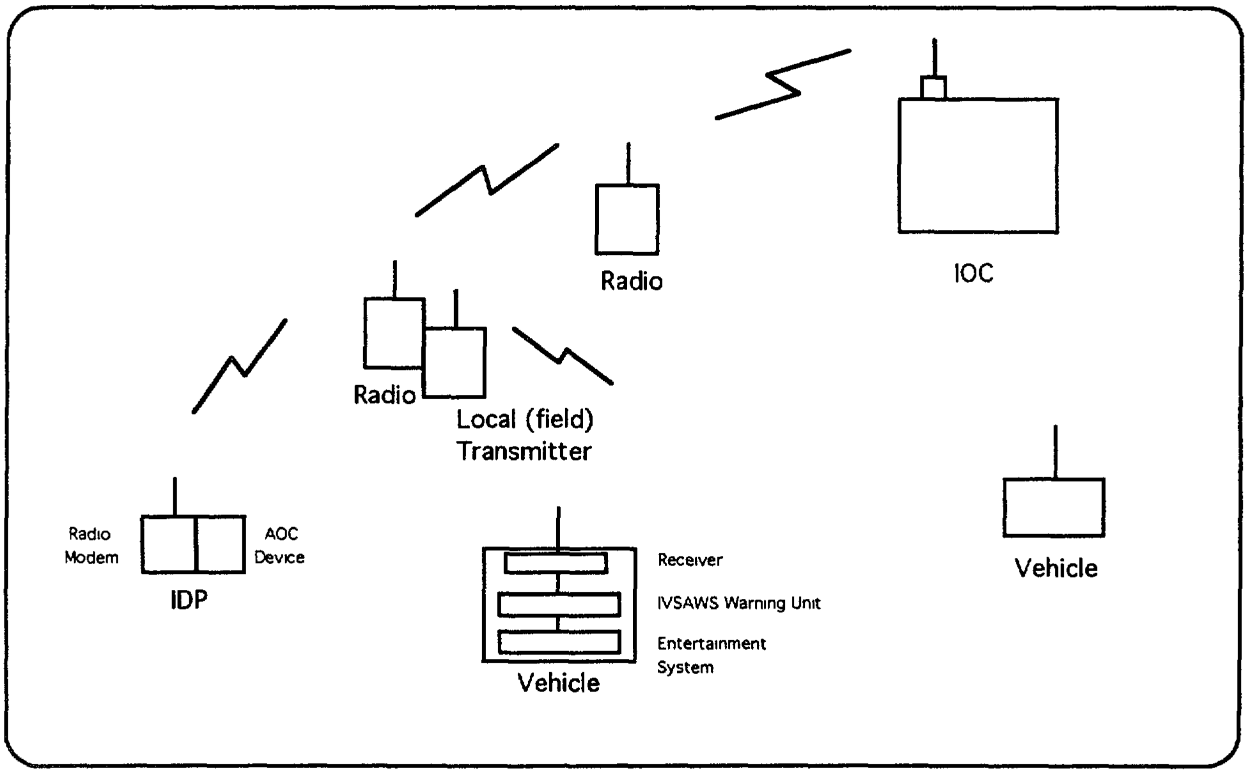

Figure 2.5.2-1 Shared Channel Block Diagram

2.5.3 Microwave

System Description

Microwave communication provides an alternative to leased line and fiber optic backbones. In areas where conduit is expensive or impossible to install and a connection to a leased line is not practical, microwave should be considered.

Microwave signals radiated from an antenna propagate through the atmosphere along a line-of-sight path. A line of sight radio link in the microwave frequency bands is made up of terminal radios and often one or more repeaters depending on the distance of the link. The frequencies used must be unique in that area to prevent interference from other microwave transmissions. Because of this constraint, microwave frequencies are licensed by the FCC, and it can be very difficult to obtain a microwave frequency allocation in crowded urban areas. When frequencies are available, they are usually in the higher frequency bands (18 and 23 GHz), which have reduced transmission distances. Microwave links may be relocated easily but require FCC coordination and approval for each end of a link that is moved.

Frequency

Microwave frequencies are those frequencies in the range above 1 GHz. The frequencies are currently allocated by the FCC for private and common carrier use and are in the 4, 6, 10, 11, 12, 13, 18, 23, and 28 GHz bands, the lower channels (2-12) are used for long haul transmissions.

Data Rates

Data transmission is available for speed rates of either DS-1 (1.544 Mbps) or DS-2 (6.312 Mbps) or DS-3 (44.736 Mbps or) as described in the Bell Pub 43801 for digital channel banks.

Coverage

A microwave line of sight permits very high bandwidth communications. Microwave transmission requires a line of sight path with relay towers spaced according to the frequency range listed below:

2 GHz and 6 GHz	**30 miles**
18 GHz	**15 miles**
23 GHz	**10 miles**

Status

The radio frequency propagation is subjected to numerous technical problems including propagation characteristics of the frequency band, natural and man-made interference, reflection, and noise. Line-of-sight networks encounter the most difficult environment in terms of propagation. Microwave radio paths over several miles long may suffer from fading, and the longer the path, the more the transmission is prone to fading. Fading is caused by atmospheric changes or ground and water reflections in the propagation path.

Microwave equipment is designed to yield a 99.95% reliability rate. With the available frequency bands, microwave transmission will experience attenuation limitations, thus reducing its reliability. Protected configurations ensure that the failure of key components will not disrupt traffic. Analog and Digital microwave equipment is readily available in the market and replacement or spare parts is not exposed to any problem in the future.

As stated before, frequencies used must be unique in that area to prevent interference from other microwave transmissions. Because of this constraint, microwave frequencies are very difficult to obtain in crowded urban areas.

Cost

IOC
TBD

Field (IDP or fixed site)
TBD

End-User
N/A

System Interfaces

The interfaces are expected to be commercial standard such that existing equipment is capable of being interfaced to the Microwave user unit.

Diagram

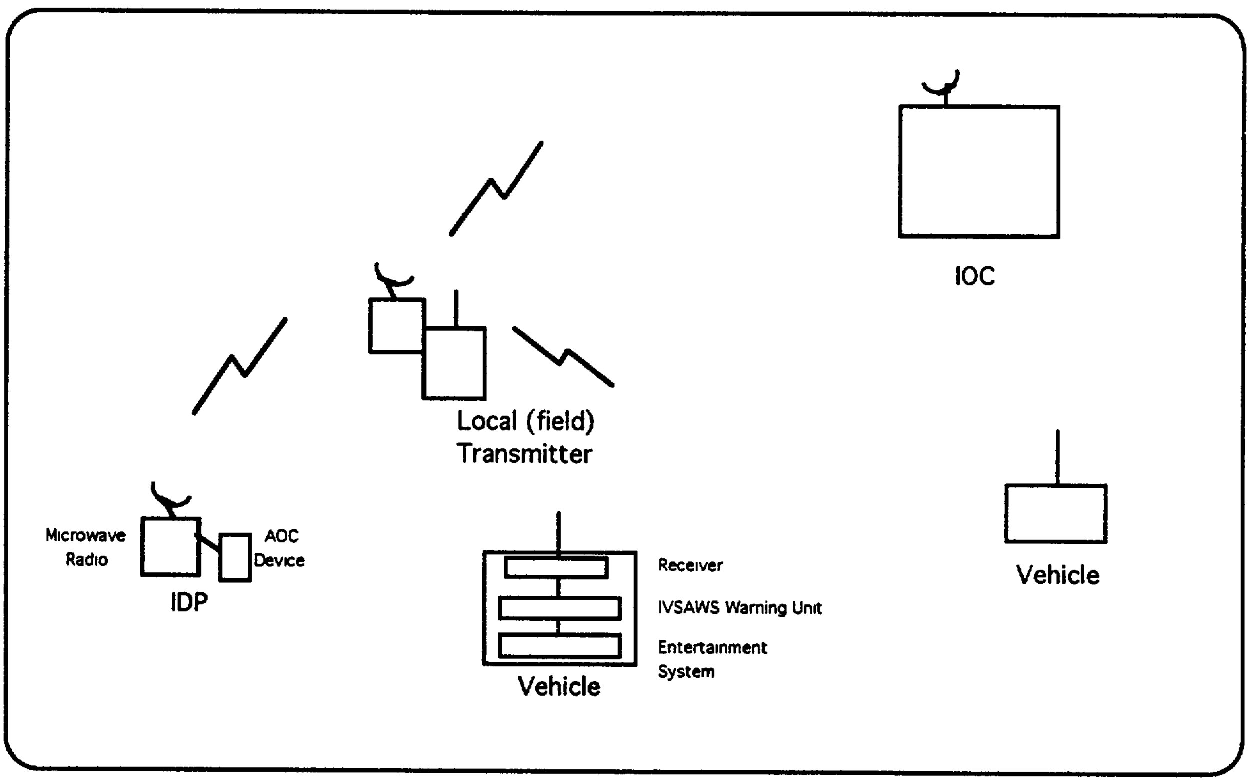

Figure 2.5.3-1 Microwave Block Diagram

3.0 Position Determination Architecture

Several position determination architectures were reviewed to provide the Area of Coverage (AOC) statistics for the IVSAWS system. The systems ranged from FM ranging to satellite ranging, all with varying levels of accuracy. Considering the cost factor, the FM ranging would certainly appease the masses, whereas the GPS system would provide the most accurate location data.

3.1 Position Information Navigation System

System Description

The Terrapin Corporation has developed the Position Information Navigation System (PINS). PINS is a terrestrial positioning system that determines location by using FM radio station broadcast. The PINS calculates position by combining signals from at least three FM stations with data from a known reference station.

The system uses a triangulation technique much the same as a Global Positioning System (GPS). The system measures the drift in the 19 kHz pilot tone signal. The system is not limited to FM, other transmit systems such as AM, cellular or TV could also be used. An advantage to using FM, the reference station could also be used as the Radio Data System station. In this way, the same receiver used in a vehicle for FM reception could be used to receive traffic information. The system is capable of a 20 meter accuracy.

Frequency

The PINS works on the 19 kHz pilot tone used in all FM radio stations. The drift is measured from at least three stations and a reference station.

Data Rate

Each FM station is allowed a 15 kHz voice channel. The maximum data rate expected form a radio signal is theoretically 7500 bps. The reference station could therefore be used to transmit traffic information in urban areas with a minimum investment.

Coverage

The service area of the PINS system is expected to be the urban areas where FM stations are abundant. Rural areas can be covered in those areas where at least three FM stations provide coverage. The possibility of using AM stations will increase the coverage area in those locations where there is insufficient FM coverage.

Status

PINS testing began in February, 1992 in Orange County, CA by the Terrapin company. Terrapin has secured financing for the PINS system and is expecting to begin production of PINS in the third quarter of 1993. Terrapin has filed for a U.S. patent for its PINS system.

Cost

The PINS system is expected to be a lower cost alternative to Loran-C and GPS. Initially, PINS units will cost approximately $200 decreasing to a final cost of $100. The FM reference station is estimated to cost approximately $10,000. The reference stations will be needed in those cities where PINS is used.

System Interfaces

The PINS unit is expected to interface directly to the antenna and FM radio provided with nearly every automobile built for the U.S. market. The PINS will be capable of interfacing to other ATIS functions such as map data to

provide current map matched position or absolute position as requested by the PINS user.

Diagram

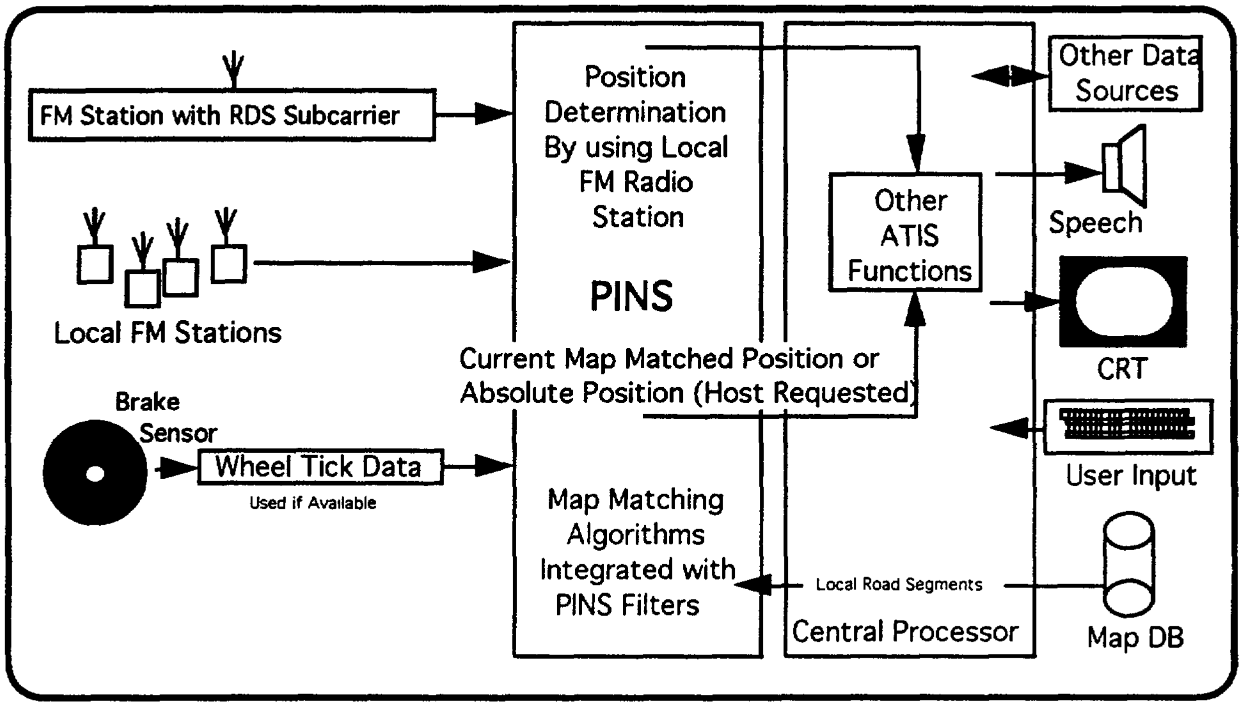

Figure 3.1-1 Terrapin's PINS Block Diagram

3.2 Global Positioning System

System Interfaces

The Global Positioning System (GPS) is a constellation of 18 - 24 satellites used to accurately determine position. The GPS system provides accuracy of 25-50 meters in normal operations mode. The GPS system is owned and operated by the U.S. Department of Defense, which has the capability to use a Selective Availability (SA) mode which degrades the position accuracy to within 100 meters.

Several GPS equipment manufactures offer a package of Differential GPS. Differential GPS is provided by placing a GPS receiver in a fixed and known location and determining the GPS offset provided by the GPS SA mode. The GPS offset is then communicated with the vehicles, the offset applied to the received GPS data, and the position accuracy determined to within 5-15 meters.

The GPS drawback is found in urban areas. GPS is a line-of-sight location determination system. The GPS system may be inhibited when used in center city areas where tall buildings will obstruct the view of the satellite system.

Frequency

The satellite signals are transmitted at two L-band frequencies, L1 of 1575.42 MHz and L2 of 1227.6 MHz. This is done to permit corrections for ionospheric delays in propagation.

Data Rate

The position information is communicated at 50 bps on both the L1 and L2 frequencies simultaneously. The message is 1500 bits long, is broken into five subframes of six seconds each, and requires 30 seconds to transmit. The data are transmitted in non-return to zero (NRZ) format.

Coverage

The GPS is a worldwide navigation system. The coverage is expected to be the surface of the earth. The coverage in the continental U.S. is comprehensive.

Status

The GPS is operational today throughout the U.S. and is being used to provide Automated Vehicle Location (AVL) services. Several equipment manufactures provide GPS units for personal use.

Cost

The cost of personal GPS for the automobile is in the $500 range and is expected to be reduced to around $200 in the near future.

System Interfaces

The interfaces to the GPS units are typically RS-232 in the DB 9-pin configuration or RS-422 in the DB 1 S-pin configuration. These interfaces are commercially available and low cost. Several radio modem and mobile data modem manufactures include a GPS port for location reporting.

Diagram

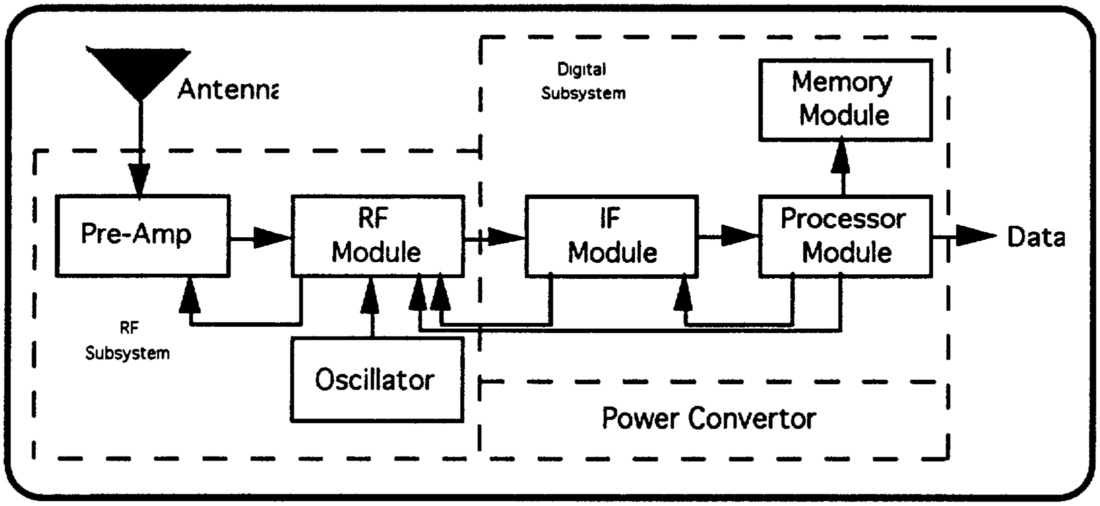

Figure 3.2-1 GPS Block Diagram

3.3 Loran-C

System Description

Loran-C is a long range hyperbolic radio navigation system. Currently, there are 17 chains consisting of 50 transmitting stations. The system is highly accurate at distances of 800 to 1000 nautical miles. The absolute accuracy has been determined to be one quarter mile and the relative accuracy is 100 feet relative. The Loran-C system is not accurate enough for the IVSAWS application.

The master station transmits synchronized, phase-coded pulses followed by the secondary stations in the chain. The master station transmits 8 pulses which are one millisecond apart followed by a ninth pulse two milliseconds later. The master station is followed in turn by the secondary stations at a prescribed interval. The secondary stations transmit pulses which are out of phase with the master station to differentiate them from the master station. The receiver then calculate position based on the time delays received and expected for the signals received.

Frequency

The signals are transmitted at 100 kHz. The phase coding allows the receiver to differentiate from the ground wave and the sky wave on reception.

Data Rate

The position information is communicated via the pulses and fixed locations of the transmit stations. There is no data rate involved in Loran-C.

Coverage

The Loran-C is a worldwide navigation system. The coverage is expected to be the surface of the earth. The coverage in the continental U.S. is comprehensive.

Status

The Loran-C is operational today throughout the world and is being used to provide nautical navigation services. Several equipment manufactures provide Loran-C units for boating use.

Cost

The cost of Loran-C has not been researched.

System Interfaces

The interfaces to the Loran-C units have not been researched.

Diagrams

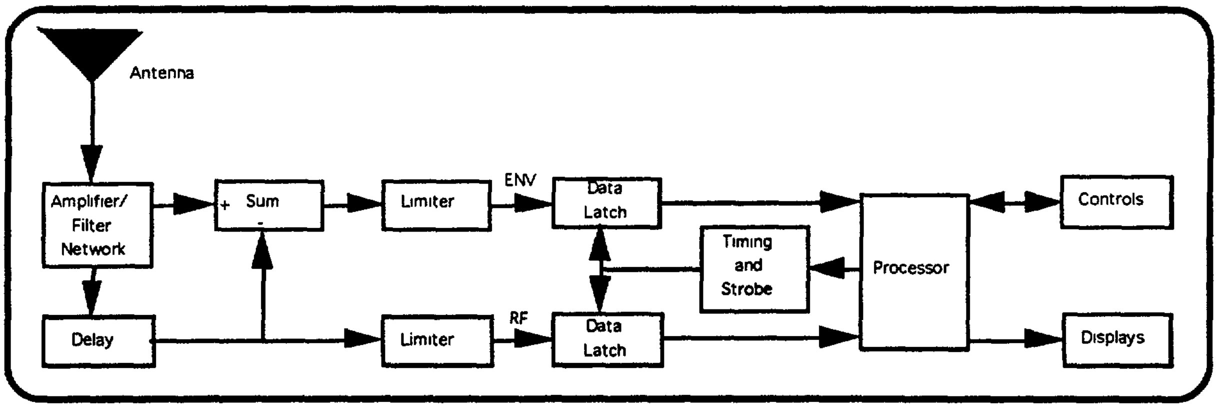

Figure 3.3-1 Loran-C Block Diagram

4.0 Architecture Functionality Trade-offs

4.1 Communications

As was stated in the IVSAWS functional definition document, there appears to be no IVSAWS without a frequency allocation. Currently the commercial cellular, paging, and mobile and land frequencies are allocated and the IVSAWS would have to lease time from the carriers. Not only does leasing involves recurring costs for the IOC as well as the driver, the most limiting factor is that a continuous frequency availability will not occur throughout the United States. Cellular and packet radios, for example, do not cover rural areas, in some urban areas the market is almost completely saturated for trunking and cellular.

Considering the cost of a system from a drivers point of view, the FM sideband combination of RBDS and SCA may prove most cost affective. The RBDS provides for text and position data, the SCA provides the voice. The out of pocket expense to the driver would be the cost of a car stereo with RBDS capabilities (planned for most domestic vehicles over the next few years) and the cost of the IVSAWS warning unit. The unfortunate limitation, at this point, is that there is no scanning capabilities within the RBDS receivers so the station that contains the RBDS would always have to be tuned in, a possible alternative would be to have the IVSAWS warning unit include a FM scanner to find the RBDS messages.

Without a specific frequency to call its own IVSAWS may find that a combination of technologies could ultimately provide the best offering, as far as cost and data transmission, for the IVSAWS system. Examples of combinations could include the following:

> Example #1 :
>
> LPHAR transmitting AM at fixed sites (or temporary sites) with the data getting to the remote unit via trunk radio. The IDP could send voice and data to the IOC via the same trunk radio system.

Example #2
Using RBDS and SCA to get data out to the drivers and the IOC and IDP communication architecture could be some form of point-to-point technology (cellular, trunking radio, etc.).

4.2 Position

The IVSAWS concept is highly dependent on position accuracy. The ability to determine vehicle location and direction of travel are of paramount importance for dissemination of advisories and warnings. There are three major players in the radio location arena. GPS is a worldwide positioning system usable in the air, on land and on sea. Loran-C is mostly used in the sea environment and the expected accuracy is commensurate with that arena. Finally, there is radio location based on the broadcast mediums.

The GPS solution is limited by the Selective Availability mode of operation which is controlled by the U.S. Department of Defense. To alleviate this limitation, differential GPS is used to provide the corrections necessary for accurate GPS positioning. The differential GPS corrections need a broadcast frequency which can be monitored by the IVSAWS. The frequency used should be standard throughout the U.S. to ensure ease of implementation. The broadcast frequency could then be used to provide the IVSAWS data.

The broadcast medium solution can be linked to the frequency allocation issue. Without a fixed pilot station to take known measurements from, this solution will require pilot stations which are different in each market. The pilot station could also be used to broadcast the IVSAWS data. The radio location could then be accomplished by measuring AM, FM, TV or cellular broadcast channel distances and direction determined by the change in location.

4.3 IVSAWS Functionality

4.3.1 Frequency Allocation

Communication Architecture	Frequency
LPHAR	Am transmission band
AHAR	Lower Land/Mobile frequency bands
HAR	AM transmission band
RBDS/SCA	FM transmission sideband
SAP	TV transmission sideband
T-Net	up to 900 MHz
Cellular	824.04 - 848.97 MHz 869.04 - 893.97 MHz
IRIDIUM	1.8 - 2.2 GHz
Impulse Radio	1 .0 to 2.0 GHz
Packet-Data Wide-Area Network	Higher Land/Mobile frequency bands
Trunk Radio	403 to 512 MHz 806 to 870 MHz
Shared Channel	29.7 to 50 MHz 66 to 88 MHz 150 to 174 MHz 403 to 512 MHz 806 to 870 MHz 900 MHz
Microwave	4, 6, 10, 11, 12, 13, 18, 23, and 28 GHz

Table 4.3.1-1 - Frequency Allocation

LPHAR

Transmission must be secondary non-interfering, no licensing required.

AHAR

Licensing required

HAR

TIS license is required from FCC, there is no fee for a government agency. Obtaining same channel across country - could be difficult, consideration should be given to using one of the newer frequencies (e.g. 1700)

RBDS/SCA

Sideband leased from the FM station

SAP

Sideband lease from TV station

T-Net

The FCC has not determined if the technology could be used on an already allocated TV frequency.

Cellular

License required from FCC. If license is already obtained (which is going to be the case) leasing of air time for both transmitter and receiver. Urban markets are almost saturated, and the systems are not widely available in non-urban areas

IRIDIUM

Monthly leasing for both IOC and end-users. Charges for air time for outgoing transmissions only

Impulse

Application filed for use as a Personal Communications System (PCS) alternative in the Bell Atlantic service area. FCC approval has not as yet been granted.

Packet-Data Wide-Area Network

Leasing based on transmission (packets sent). The technology is not currently available in non-urban areas

Trunk Radio

Licensing is required for channels used. If license is already obtained (which is going to be the case) channel may be leased from the licensee (varies).

Shared Channel

Licensing is required for channels used. If license is already obtained (which is going to be the case) channel may be leased from the licensee (varies).

Microwave

Microwave technology is saturated in urban markets, and not widely available in non-urban areas

4.3.2 Define Area of Coverage

The communication architecture's capability to transmit AOC information between the IVSAWS users is indicated in table 4.3.2-l.

Architecture	IDP to IOC	IDP to Vehicle	IOC to Vehicle	IOC to Field
LPHAR	N/A	V	V	N/A
AHAR	N/A	V, D	V, D	N/A
HAR	N/A	V	V	N/A
RBDS/SCA	V, D	N/A	V, D	V,D
SAP	V, D	N/A	V,D	V,D
T-Net	V, D	V,D	V,D	V,D
Cellular	V, D	V, D	V, D	V, D
IRIDIUM	V, D	V, D	V, D	D
Impulse	V, D	V, D	V, D	V, D
Packet Data	D	V, D	V, D	V, D
Trunk Radio	V, D	See note	See note	V, D
Shared Channel	V, D	See note	See note	V,D
Microwave	V, D	N/A	N/A	v, D

Table 4.3.2-l - Transmission Capability

Legend:

D - Data

V - Voice

N/A - Non-applicable

Notes:

LPHAR

IDP to Vehicle

Technology lends itself to fixed or temporary sites, voice only, local broadcasts.

AOC cannot be selected, however, the coverage lends itself to omnidirectional broadcasting up to 1/2 mile from the transmitter. Usage of directional antennas could assist in the narrowing of the coverage.

AHAR

IDP to IOC

Data transmission limited to tones, not well suited for AOC data.

IDP to Vehicle

AOC limited by the transmitter power. Coverage is omnidirectional. Usage of directional antennas could assist in the narrowing of the coverage.

HAR

IDP to Vehicle

Technology lends itself to fixed or temporary sites, voice only, local broadcasts

AOC cannot be selected, however, the coverage lends itself to omnidirectional broadcasting from the transmitter. Usage of directional antennas could assist in the narrowing of the coverage.

T-Net

IDP to Vehicle

Voice and digital (AOC) data capabilities, but only via the main transmitter not directly.

Trunk Radio

IDP to Vehicle

Monetarily not feasible

IOC to Vehicle

Monetarily not feasible

IOC to field

Ideal for sending data from IOC to each fixed field transmitter device

Shared Channel
- IDP to Vehicle
  - Monetarily not feasible
- IOC to Vehicle
  - Monetarily not feasible
- IOC to field
  - Ideal for sending data from IOC to each fixed field transmitter device

Microwave
- IDP to IOC
  - Transmission of voice and data from parked mobile unit
- IOC to field
  - Ideal for sending data from IOC to each fixed field transmitter device

4.3.3 Refine Zone Location

TBD

4.3.4 Tailor IVSAWS Message

Table 4.3.4-1 lists the digital data transfer capability for each communication architecture listed in the study.

Comm. Architecture	Data Rate	User Defined Format
LPHAR	N/A	N/A
AHAR	up to 9.6 kbps	Yes
HAR	N/A	N/A
RBDS/SCA	up to 1200 bps	No
SAP	up to 19.2 kbps	Yes
T-Net	up to 16 kbos	Yes
Analog Cellular	up to 4800 bps	Yes
Digital Cellular	up to 48.6 kbps	Yes
IRIDIUM - Voice	up to 4800 bps	N/A
IRIDIUM - Data	up to 2400 bps	Yes
Impulse	upto 1 Gbps	Yes
Packet Data	up to 19.2 p	Yes
Trunk Radio	upto 9.6 kbps	Yes
Shared Channel	upto 9.6 kbps	Yes
Microwave	up to 44.736 Mbps	Yes

Table 4.3.4-I - Communication Architecture Transfer Rate

4.3.5 Generate Alert

The Communication architecture's shall provide for the following warning and advisory zone coverage for all major secondary roads in the United States.

LPHAR

Able to be used throughout the U.S. Limitations come in frequency selections due to the "secondary non-interfering" limitation placed on the transmission. Each area has different AM frequencies being used.

AHAR

See Shared Channels.

HAR

Able to be used throughout the U.S. Limitations come in frequency selections due to AM frequencies being used randomly throughout the U.S. Possibility of utilizing one of the newer frequencies (e.g. 1700) through most of the country.

RBDS/SCA

Available wherever FM stations have transmission coverage. No consistent frequency will be able to be used due to inability to lease sidebands and some frequencies are not utilized in all areas. IVSAWS warning unit will have to provide scanning capabilities.

SAP

Available wherever TV stations have transmission coverage. No consistent frequency will be able to be used due to inability to lease sidebands and some frequencies are not utilized in all areas. IVSAWS warning unit will have to provide scanning capabilities.

T-Net

The technology is new and not currently set-up. IVSAWS, providing FCC approval for sharing TV frequencies, would have to set up the systems.

Cellular

The available cellular frequencies should all be controlled, meaning that the only cellular available would be through leasing. Most urban areas are saturated, but rural areas are less than adequately covered.

IRIDIUM

The consortium was formed in 1991 and is expected that the first 7 satellites will be launched, the system control facility will be operational, and four gateways will be operational in 1994; early Iridium service will be available and the full constellation will be deployed by 1996; and the Iridium system and additional gateways will be fully operational by 1997.

Impulse

Initial operation area is expected to be in the Bell Atlantic operation zone. Individual license could be applied for, however, manufacture is exploring use in the Personal Communications System (PCS) market.

Packet-Data Wide-Area Network

Available in most urban areas, currently not offered in rural areas. License to transmit in rural areas required, along with transmitters and all applicable hardware.

Trunk Radio

The available trunking frequencies should all be controlled, meaning that the only trunking available would be through leasing. Most rural areas are less than adequately covered.

Shared Channel

The available frequencies should all be controlled, meaning that most of the shared channel frequencies would be obtained through leasing. Most rural areas are less than adequately covered.

Microwave

Frequencies in urban areas taken, so either there is microwave available to lease or not available at all. If planning on utilizing technology in rural areas with no current coverage, licensing and transmission facilities will be required.

4.3.6 Alert Driver

The Communication architecture provides, in some cases, error detection and recovery to help minimize the false alarm rate and maximize the percentage of messages that get to the driver. Table 4.6.3-I shows which architecture's provide error detection and correction.

Communication Architecture	Error Detection/Recovery
LPHAR	No
AHAR	No
HAR	No
RBDS/SCA	Yes
SAP	Yes
T-Net	Unknown
Analog Cellular	No
Digital Cellular	Yes
IRIDIUM	No
Impulse	Unknown
Packet-Data Wide Area Network	Yes
Trunk Radio	Yes (data only)
Shared Channel	Yes (data only)
Microwave	Yes

Table 4.3.6-I - Error Detection and Recovery Capability

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APPENDIX P:
IVSAWS WAVEFORM DESIGN #l
(NARROWBAND COMMUNICATION WITH GPS AOC CONTROL)

This appendix describes an IVSAWS communication waveform compatible with a system architecture utilizing narrowband communication and GPS-based area of coverage (AOC) control.

1. MODULATION

The modulation method used shall be $\frac{\pi}{4}$ shifted, differentially encoded quadrature phase shift keying as described in paragraphs 1.3 through 1.5. Paragraph 1.1 describes the forward error correction technique to be applied prior to modulation. Paragraph 1.2 describes codeword interleaving.

1.1 Forward error correction (FEC). The binary data stream entering the modulator, b_m, shall be converted into two separate binary streams, M_k and N_k, via a convolutional encoder. The encoder shall be a 1/2 rate constraint length seven (k = 7) convolutional encoder.

1.1.1 1/2 rate encoding. A block diagram of the rate 1/2, k=7 encoder is shown in Figure 1.1.1-1. The generating functions, denoted as GO and G1, shall be 1111001 (binary) and 1011011, respectively. At each b_m bit input, the data stream is convolved with the generating functions to produce two codewords, M_k and N_k.

1.2 Interleaving. The codewords M_k and N_k shall be written into an interleaving matrix, row-wise, as shown in Figure 1.2-1. The codewords shall be read by columns, two at a time, to produce the binary data sequences X_k and Y_k.

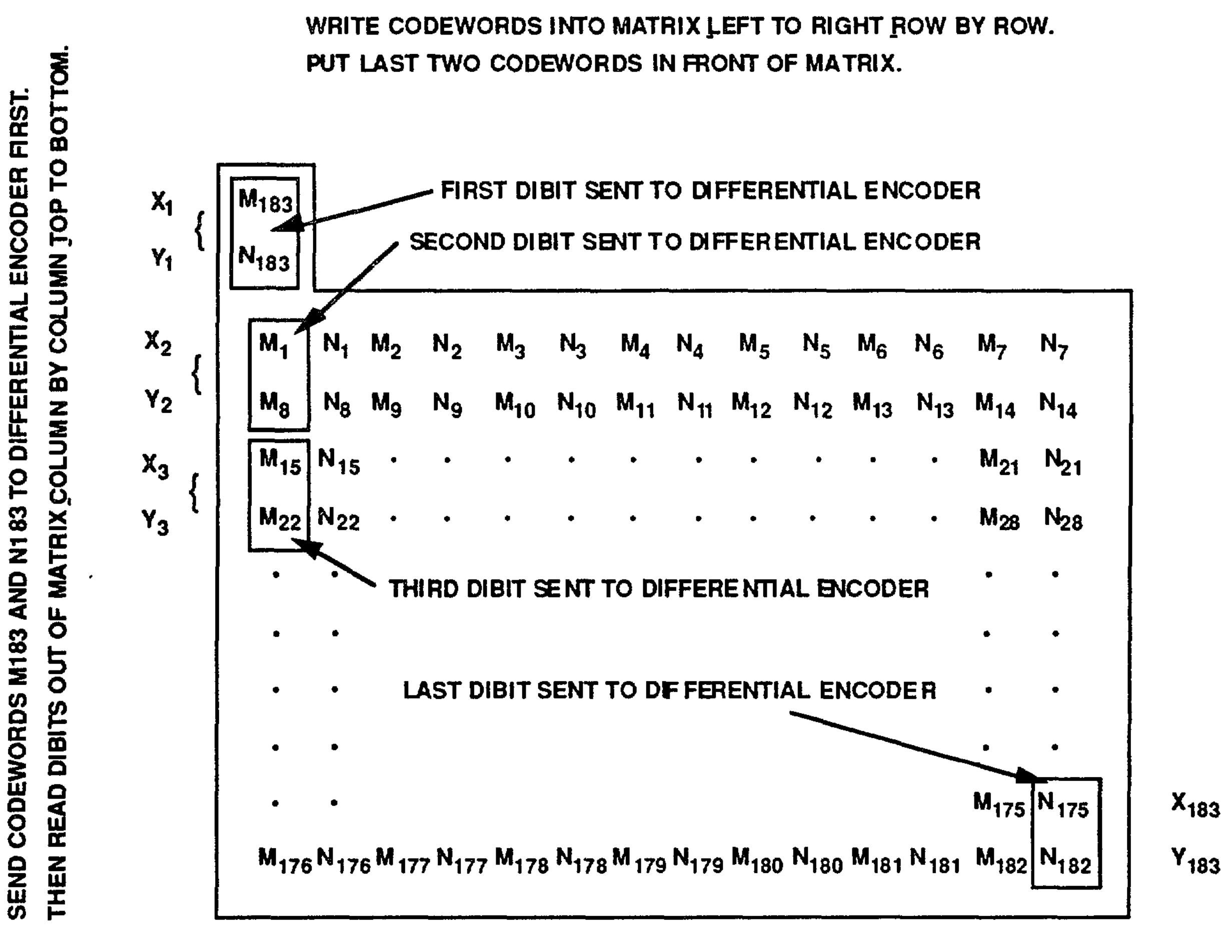


Figure 1.2-1. Codeword interleaver.

1.3 Differential encoding. The binary data sequences X_k and Y_k are differentially encoded onto I_k and Q_k according to:

$$I_k = I_{k-1} \cos[\Delta\Phi(X_k,Y_k)] - Q_{k-1} \sin[\Delta\Phi(X_k,Y_k)]$$
$$Q_k = I_{k-1} \sin[\Delta\Phi(X_k,Y_k)] + Q_{k-1} \cos[\Delta\Phi(X_k,Y_k)]$$

where I_{k-1}, Q_{k-1} are the amplitudes at the previous pulse time. The phase change $\Delta\Phi$ is determined according to Table 1.3-1.

Table 1.3-1. Differential phase code.

X_k	Y_k	$\Delta\Phi$
0	0	$\frac{\pi}{4}$
0	1	$\frac{3\pi}{4}$
1	0	$\frac{-\pi}{4}$
1	1	$\frac{-3\pi}{4}$

The signals I_k, Q_k at the output of the differential phase encoding block can take one of five values, $0, \pm 1, \pm\frac{1}{\sqrt{2}}$, resulting in the constellation shown in Figure 1.3-1. Odd (denoted ⊕) and even (denoted ⊗) symbol constellations are offset by $\frac{\pi}{4}$ radians.

1.4 Baseband filtering. Impulses I_k, Q_k are applied to the inputs of the I & Q base-band filters. The base-band filters shall have linear phase and square root raised cosine frequency response of the form:

$$|H(f)| = \begin{cases} 1 & 0 \le f \le \frac{(1-\alpha)}{2T} \\ \sqrt{\frac{1}{2}\left\{1 - \sin\left[\frac{\pi(2fT-1)}{2\alpha}\right]\right\}} & \frac{(1-\alpha)}{2T} \le f \le \frac{(1+\alpha)}{2T} \\ 0 & f > \frac{(1+\alpha)}{2T} \end{cases}$$

where T, the symbol period, is equal to twice the reciprocal of the baseband data rate (6075 bits per second). The roll-of factor, α, determines the width of the transition band, and is 0.35.

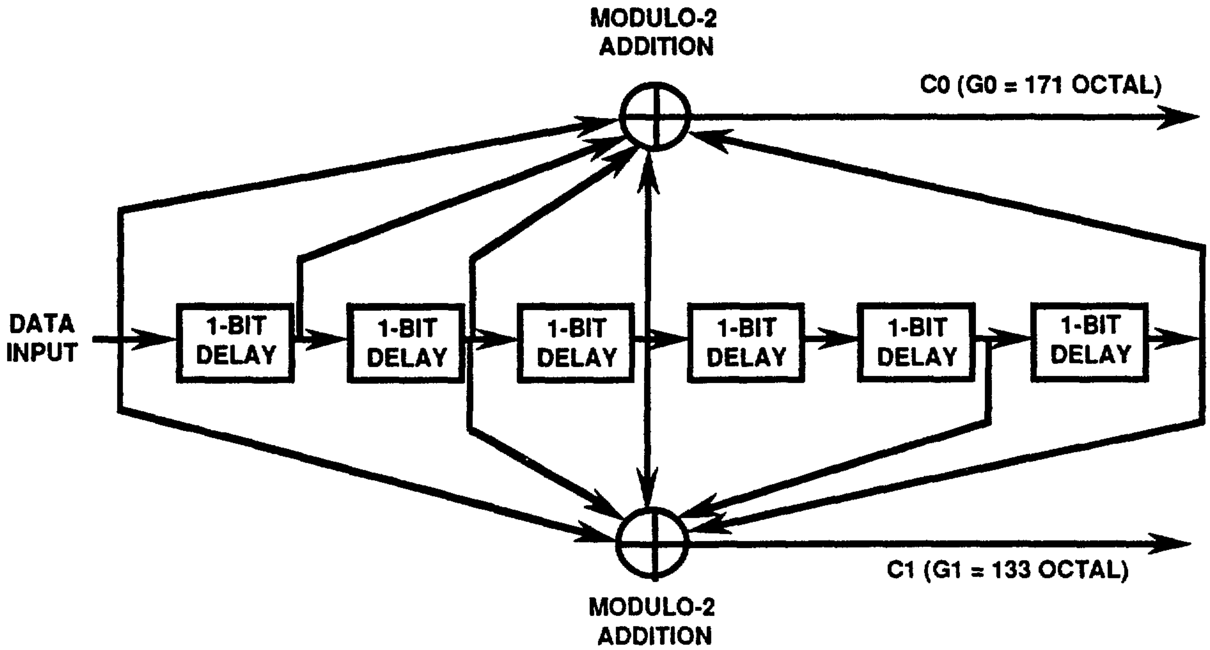


Figure 1.1.1-1. Constraint length 7 half-rate convolutional encoder.

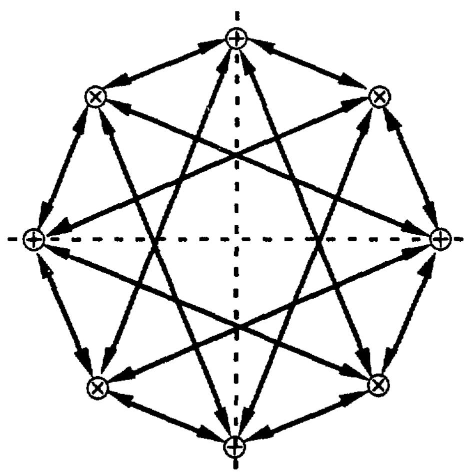


Figure 1.3-1. $\frac{\pi}{4}$ shifted, differentially encoded QPSK constellation.

1.5 Modulation at radio frequency (RF). Symbols are transmitted as changes in phase rather than absolute phases. The resultant transmitted signal s(t) is given by:

$$s(t) = \sum_n h(t - nT)\cos\Phi_n \cos\omega_c t - \sum_n h(t - nT)\sin\Phi_n \sin\omega_c t$$

where h(t) is the baseband filter impulse response (finite), ω_c is the radian carrier frequency, T is the symbol period, and Φ_n is the absolute phase corresponding to the n^{th} symbol interval. The Φ_n which results from the differential encoding is:

$$\Phi_n = \Phi_{n-1} + \Delta\Phi_n.$$

Figure 1.5-1 illustrates a block diagram of the modulation process from binary data input, b_m, through signal output, s(t).

[FHWA P-6]

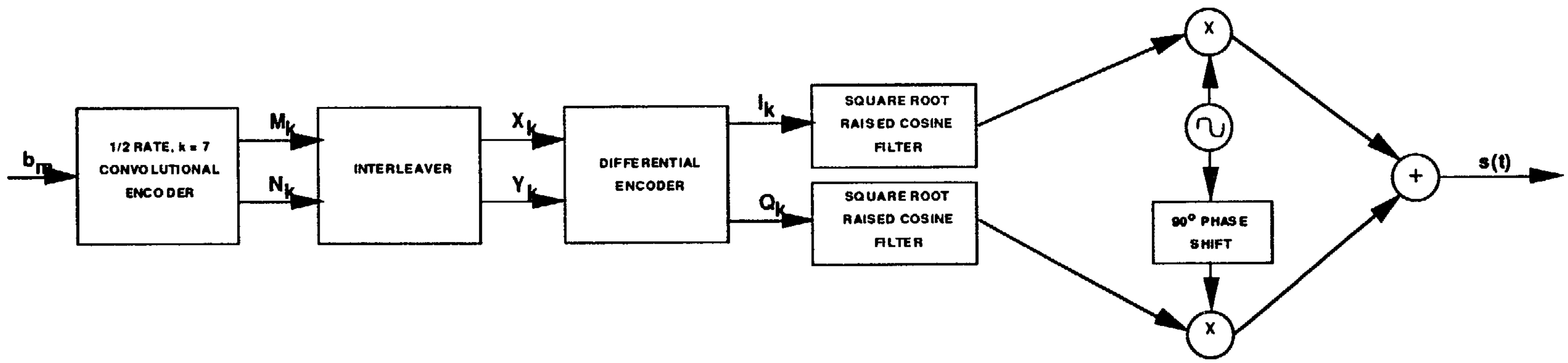


Figure 1.5-1 Modulator block diagram.

2. TRANSMITTER OUTPUT

2.1 Operating frequencies. Radios shall operate one channel of the 220-222 MHz band. The channel consists of a frequency pair separated by 1 MHz. Table 2.1-1 lists the operating frequencies and channel assignment.

Table 2.1-1. IVSAWS operating frequencies in the 220-222 MHz band.

TBD

IVSAWS can operate effectively using a single 220-222 MHz channel (nationwide allocation). Hughes strongly recommends that the FHWA pursue an IVSAWS allocation in this band.

2.2 Frequency tolerance. Frequency tolerance for base stations shall be 0.1 ppm. Frequency tolerance for mobile units shall be 1.5 ppm.

2.3 Spectral containment. The required emissions mask shall be as specified in paragraph 102 of the Amendment of Part 90 of the Commission's Rules to Provide for the 220-222 MHz Band by the Private Land Mobile Radio Services. Figure 2.3-1 illustrates the specified emissions mask. Power is relative to the maximum ERP (see paragraph 2.4).

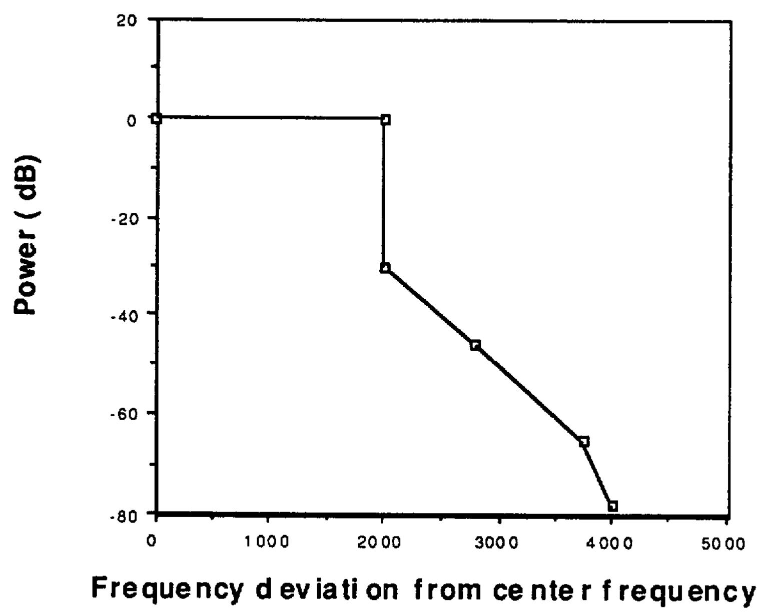


Figure 2.3-1. IVSAWS emissions mask.

2.4 Transmit power. Transmitter power shall be as specified in paragraphs 115 and 116 of the Amendment of Part 90 of the Commission's Rules to Provide for the 220-222 MHz Band by the Private Land Mobile Radio Services.

3. SIGNAL STRUCTURE

3.1 Introduction. This section provides definition of the alert signal structure. Included are: message format and bit structure, coding, framing and synchronization.

3.2 Frame structure. Each frame shall be 6075 bit periods in duration. The frame structure is shown in figure 3.2-1. Each frame is divided into three timeslots designated slot 1 through slot 3. Over-the-air signalling shall occur at a rate of 6075 bits per second.

3.2 Timeslot structure. Each timeslot shall be 2025 bit periods in duration. The timeslot structure is shown in figure 3.2-1. Each frame is divided into five alerts designated alert 1 through alert 5.

3.3 Message structure. The basic alert message shall consist of 183 bits of information, excluding guard time, transmitter power ramp up time, and synchronization (sync). The basic alert message structure is shown in figure 3.2-1. The 183 bits of information shall be convolutionally encoded and interleaved into a 366 bit message (see paragraphs 1.1 and 1.2). Including guard time, transmitter power ramp up time, and sync, the alert message shall be 405 bit periods in duration. In addition to the basic message type, continue, free text, delete, system time and offset, and area of coverage (AOC) extension messages are defined.

3.3.1 Guard. Alert guard shall be five bit periods in duration.

3.3.2 Transmitter power ramp up. Transmitter power ramp up shall be six bit periods in duration.

3.3.3 Synchronization. The synchronization word is a 14 symbol field used for alert synchronization and equalizer training. The sync word is specified by the following sequence of phase changes in radians:

$$-\pi/4 \quad -\pi/4 \quad -\pi/4 \quad 3\pi/4 \quad \pi/4 \quad 3\pi/4 \quad -3\pi/4 \quad 3\pi/4 \quad -3\pi/4 \quad -\pi/4 \quad 3\pi/4 \quad \pi/4 \quad -\pi/4 \quad -\pi/4$$

3.3.4 Alert type. Alert type is a 3 bit number which identifies the type of alert message being broadcast. Table 3.3.4-1 identifies the relationship between the contents of alert type and the type of message being broadcast.

Table 3.3.4-1. Alert types.

Message type	Alert type value
Basic (stationary alert zone)	0
Basic (mobile alert zone)	1
Continue	2
Delete	3
System time and GPS correction	4
Free text	5
AOC extension	6
Reserved	7

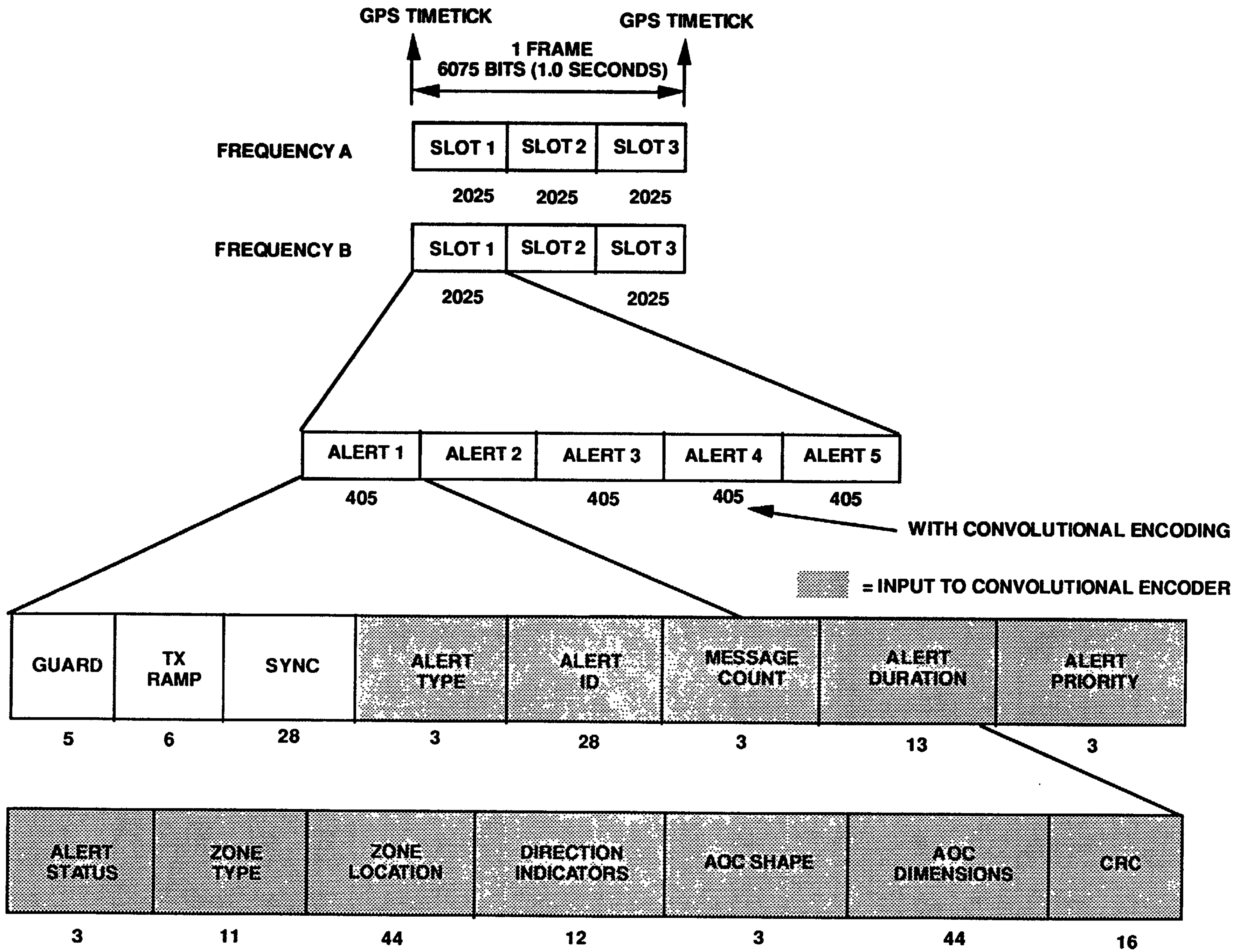


Figure 3.2-1 Frame structure.

[FHWA P-9]

3.3.5 **Basic alert message.** The basic alert message structure is shown in figure 3.2-l.

3.3.5.1 Alert ID. Alert ID is a 28 bit number that uniquely identifies an alert message. IVSAWS can issue 268435,456 alerts without alert ID reuse. Mobile units shall be assigned a unique alert ID which will be used for all alert broadcasts.

3.3.5.2 Message count. The message count shall identify the number of continue, free text, and or AOC extension messages to follow (0 -7).

3.3.5.3 Alert duration. Alert duration is a 13 bit field that specifies the time at which an alert shall be deleted from the alert database. Alert duration shall be relative to system time (see paragraph 3.3.9.3). Table 3.3.5.3-l shows the field structure.

Table 3.3.5.3-l. Allocations for alert duration.

Segment	Bits
Coarse duration	2
Time offset	11
Total	13

Coarse duration specifies the time reference of the time offset. If coarse duration is 00, time offset shall be relative to midnight of the current day (0000 hours). Time offset shall then specify the alert expiration time in terms of the number of minutes past midnight. When system time equals alert expiration time, the alert shall be removed from the vehicular database. If coarse duration is 01, time offset shall be relative to midnight of the first day of the current month. Time offset shall then specify the alert expiration time in terms of the number of hours past midnight of the first day of the current month. When system time equals alert expiration time, the alert shall be removed from the vehicular database. If coarse duration is 10, time offset shall be relative to midnight of the first day of the current year. Time offset shall then specify the alert expiration time in terms of the number of day past the first day of the current year When system time equals alert expiration time, the alert shall be removed from the vehicular database. If coarse duration equals 11, the alert can only be removed from the database via the receipt of a delete message (see paragraph 3.3.8).

3.3.5.4 Alert priority. Alert priority shall be set from 0 to 7 to indicate the relative urgency or severity of the embedded hazard or advisory message. 0 is the lowest priority; 7 is the highest priority (most severe).

3.3.5.5 Alert status. Alert status shall be set from 0 to 7 to indicate the source or condition of the embedded hazard or advisory message. Table 3.3.5.5-l correlates alert status with alert status value.

Table 3.3.5.5-l. Alert status.

Alert status	Alert status value
Confirmed	0
Unconfirmed	1
Forecast	2
Reserved	3 thru 7

3.3.5.6 Zone type. Zone type is an 11-bit pointer to one of 2048 hazard and advisory messages stored within a vehicular IVSAWS database. It identifies a message to be presented to a driver via a display or speech synthesizer. The message list used shall be a tailored version of the RDS ALERT C message list (Appendix A).

3.3.5.7 Zone location. Zone location is a 44 bit field used to identify the position of a hazard or advisory site. The grid reference system is based on the Universal Transverse Mercator (UTM) projection. As shown in Figure A, the features on the surface of the earth (from 80^{o} S latitude to 84^{o} N latitude) are projected onto a cylinder, and the cylinder is flattened to achieve 6-degree wide zones (see Figure B). A five-element term is used to designate coordinates (e.g., NN A $\alpha1$ $\alpha2$ eeeee nnnnn). The term NN refers to one of the 60 zones and the term A designates one of the 20 latitude bands, labeled C through X, in Figure B. Each UTM zone is divided into a number of 100 km squares, as shown in Figure C. Each of these grid squares has a two-character designator ($\alpha1\alpha2$) known as the alpha pair designator. The $\alpha1$ character designates the column a grid square is in and the $\alpha2$ character designates the row. The alpha pair designators occur in a normal sequence, and repeat approximately every 2,000 km north or south, and every 18 degrees east or west. Within a single grid square (see Figure C), a position can be indicated by two numbers: easting (eeeee), the distance in meters from the west edge of the grid square, and northing (nnnnn), the distance in meters from the south edge of the grid square. Since IVSAWS driver alert distances are small (less than 2 km), the grid zone designator can be dropped and an IVSAWS zone location thus has the form: $\alpha1$ $\alpha2$ eeeee nnnnn. Table 3.3.12-1 shows the zone location field structure.

Table 3.3.5-1. Field Allocations for zone location.

Station location segment	Bits
Alpha designator - column ($\alpha1$)	5
Alpha designator - row ($\alpha2$)	5
Easting (eeeee)	17
Northing (nnnnn)	17
Total	44

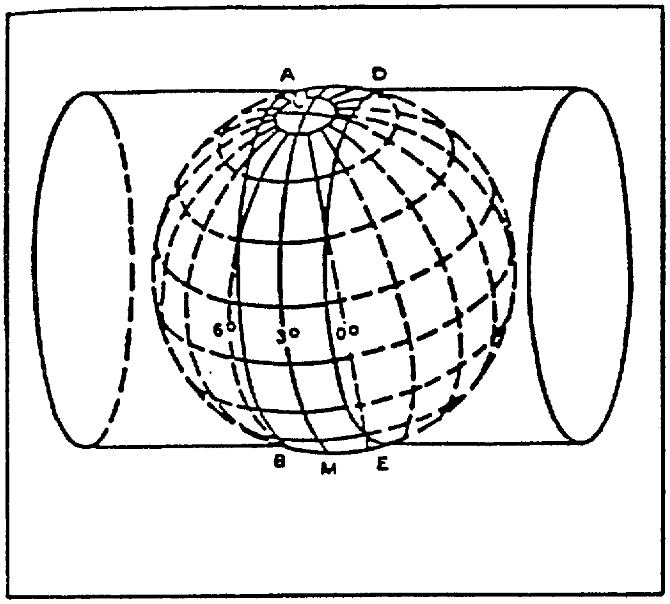


Figure A. The Traverse Mercator Projection. The cylinder is chosen slightly smaller than the earth to reduce distortion to a minimum between angles and distance on the earth as compared to the same two quantities on the map.

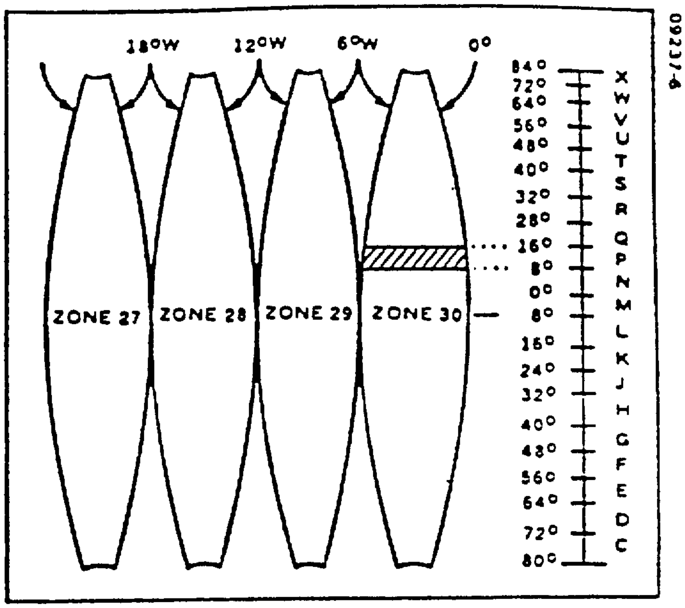


Figure B. UTM Six-Degree-Wide Standard Zones. Each zone has as its east and west limits a meridian of longitude, and one central meridian for any 6° by 8° N-S area can be determined by the column (zone) and row (alphabetic) UTM terms (e.g., the shaded area shown here is designated as 30P).

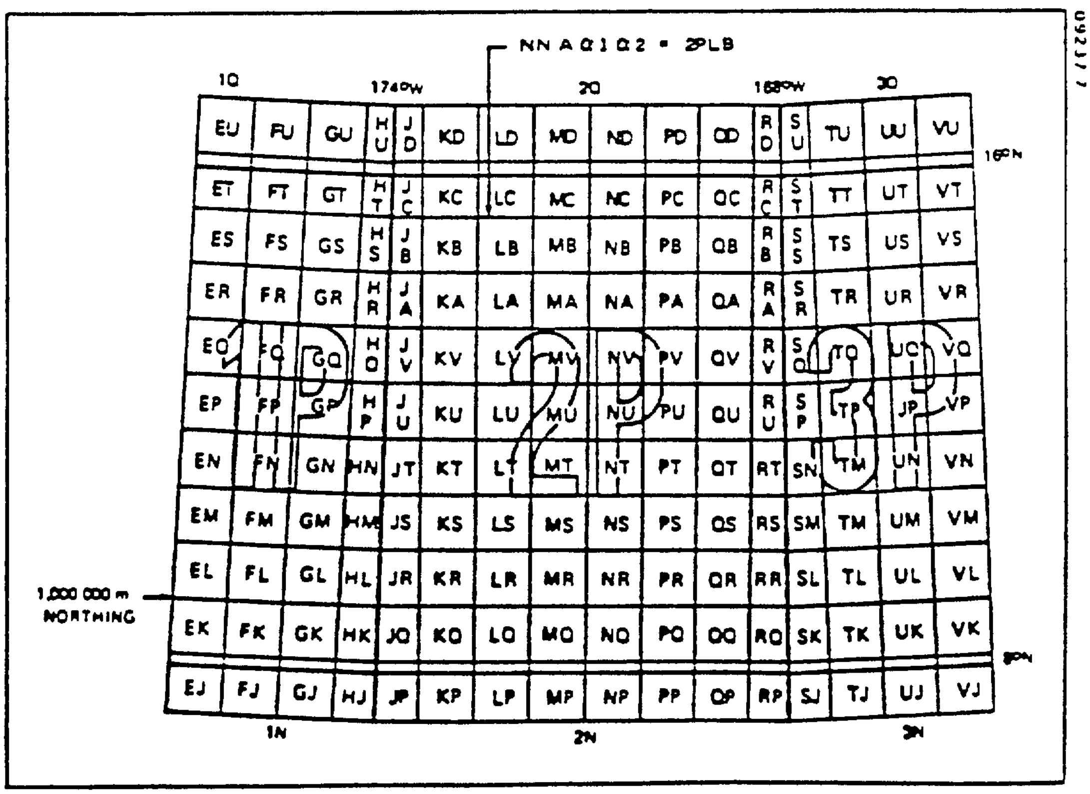


Figure C. Grid Square Designators. The letters and numbers indicate grid zone designation, 100,000 m square identification, and grid coordinates of the point expressed to the desired accuracy.

3.3.5.8 Direction indicators Direction indicators is a 12 bit field used to limit alert dissemination to vehicles based upon their direction of travel. Each bit covers a 30 degree segment (see Figure 3.3.5.8- 1). Setting a bit of this field to a 1 permits alert dissemination to vehicles travelling in the corresponding directional range. Setting a bit of this field to a 0 prohibits alert dissemination to vehicles travelling in the corresponding directional range. For example, setting all bits to 1 enables omnidirectional alert dissemination.

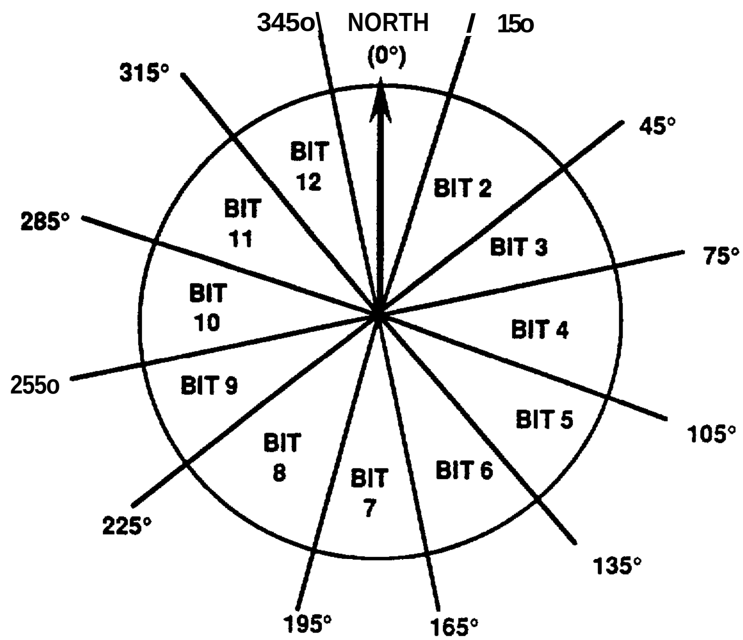


Figure 3.3.5.8-l. Direction indicator bit assignments.

3.3.5.9 AOC shape. AOC shape is a 3 bit field used to define the shape of the intended area of alert coverage. Table 3.3.5.9-l identifies valid shapes. If the shape is extended, an AOC extension message shall follow which defines the AOC dimensions (see paragraph 3.3.10).

Table 3.3.5.9-l. AOC shapes.

Shape	Value
Box	0
Circle	1
Semicircle	2
Reserved	3 thru 6
Extended	7

3.3.5.10 AOC dimensions. AOC dimensions is a 44 bit field used to define the dimensions of the area of alert coverage. The format and content of the field is AOC-shape dependent and is TBD. If the AOC shape is extended, this field shall be set to all zeros.

3.3.6 Continue message The continue message is used to extend the basic alert message. Figure 3.3.6-l shows the continue message structure.

3.3.6.1 Alert ID. The alert ID shall be set equal to the alert ID of the source basic alert message.

3.3.6.2 Message count. Message count shall identify the current continue, free text, or AOC extension message number (1 - 7).

3.3.6.3 Message extension. Message extension is subdivided into 13 subfields. Each subfield consists of a two bit header followed by an 11 bit data or pointer segment. The header can assume one of four values and identifies the type of information in the segment, as listed in Table 3.3.7.3-l. Customized messages can therefore be created by using a combination of “canned” alert message database messages and site-specific data.

Table 3.3.6.3 1. Message extension subfield contenl

Contents	P/D
Not used	0
Pointer to alert message database	1
Data	2
Reserved	3

3.3.7 **Free text message.** The continue message is used to extend the basic alert message. Figure 3.3.7-l shows the free text message structure.

3.3.7.1 Alert ID. The alert ID shall be set equal to the alert ID of the source basic alert message.

3.3.7.2 Message count. Message count shall identify the current continue, free text, or AOC extension message number (1 - 7).

3.3.7.3 Free text, Free text is a field used to send site-specific information to the driver. Typically, it could be used to identify the names of roads at which an incident has occurred (e.g. 15 at HIWAY 39).

3.3.8 Delete message. The delete message is used to erase messages from vehicular alert databases. The delete message structure is shown in figure 3.3.8-l.

3.3.8.1 Alert ID. Alert ID shall be set equal to the ID of the alert to be erased from the alert database.

3.3.9 System time and GPS correct message Each base station shall transmit a system time and GPS correction message once per second as the first alert (ALERT 1, Figure 3.2- 1) of its assigned slot. The message structure is shown in figure 3.3.9-l. Station ID, station health, and Z-count shall be transmitted with each message and are defined in Table 3.3.9-l. A system time or GPS correction field is also incorporated into each message. The correction/time (C/T) control bit identifies the field type. A system time field shall be broadcast once every three seconds. GPS corrections shall be broadcast in the remaining broadcasts. For each GPS satellite viewed by the IVSAWS base station, a GPS correction shall be broadcast. If more than four satellites are in view, alternate messages shall divide the satellite corrections.

Table 3.3.9-l. Station ID, station health, Z-count, and C/T field structures.

Field	Scale factor and units	Range	Bits
Station ID	1	0 - 65,535	16
Station health		4 states	2
Z- count	6 seconds	l-100,794 s.	17
Correction/time (C/T control	1		1

3.3.9.1 GPS satellite corrections. GPS pseudorange and range-rate corrections are used to improve the accuracy of hazard and vehicle position measurements utilizing Differential GPS. Table 3.3.9.1-1 shows the GPS correction field structure. Four subfields are broadcast with each GPS correction message.

Table 3.3.9.1-1. Subfield structure fo GPS correction.

Segment	Scale factor and units	Range	Bits
Pseudorange correction	0.1 meters	+/- 3276.8 m	16
Range-rate correction	0.004 m/sec	+/- 0.512 m/s	8
Satellite ID	1	0-31	5
Satellite health		4 states	2
Reserved			
Total			32

3.3.9.2 System time The system time (date and time of day) field will incorporate Coordinated Universal Time (UTC) and Modified Julian Day (MJD) in accordance with CCIR Recommendations 457 and 460. A coded local time difference, expressed in multiples of half-hours, is appended to the system time. Table 3.3.9.2-l shows the field structure.

Table 3.3.9.2-l. Field structure for system time.

Segment	Scale factor and units	Range	Bits
Modified Julian Day	1 day	0 - 99999 d.	17
Hour	1 hour	0 - 23 hr	5
Minute	1 minute	0-59 min	6
Local time offset	0.5 hours	+/- 12 hr	6
Reserved			94
Total			128

3.3.10 AOC extension message The AOC extension message is used to define irregular areas of coverage.Figure 3.3. 10.1 shows the message structure.

3.3.10.1 Alert ID. The alert ID shall be set equal to the alert ID of the source basic alert message.

3.3.10.2 Message count Message count shall identify the current continue, free text, or AOC extension message number (1 - 7).

3.3.10.3 AOC coordinates. The first three bits of the AOC coordinates field identifies the number of coordinate pairs (Ax, Ay) that have been incorporated into the current message (l-5). Each coordinate pair defines a vertex of the desired AOC. The coordinate positions are specified relative to the defined zone location (see paragraph 3.3.5.7). Ax and Ay can range from -4095 meters to 4096 meters. A positive Ax (Ay) specifies an abscissa (ordinate) that is north (east) of the zone location. A negative Ax (Ay) specifies an abscissa (ordinate) that is south (west) of the zone location.

3.3.11 Cyclic redundancy check (CRC). CRC is a 16 bit field used for error detection. The CRC polynomial generator shall be $X^{16} + X^{15} + X^{5} + 1$ (CRC-CCI'IT).

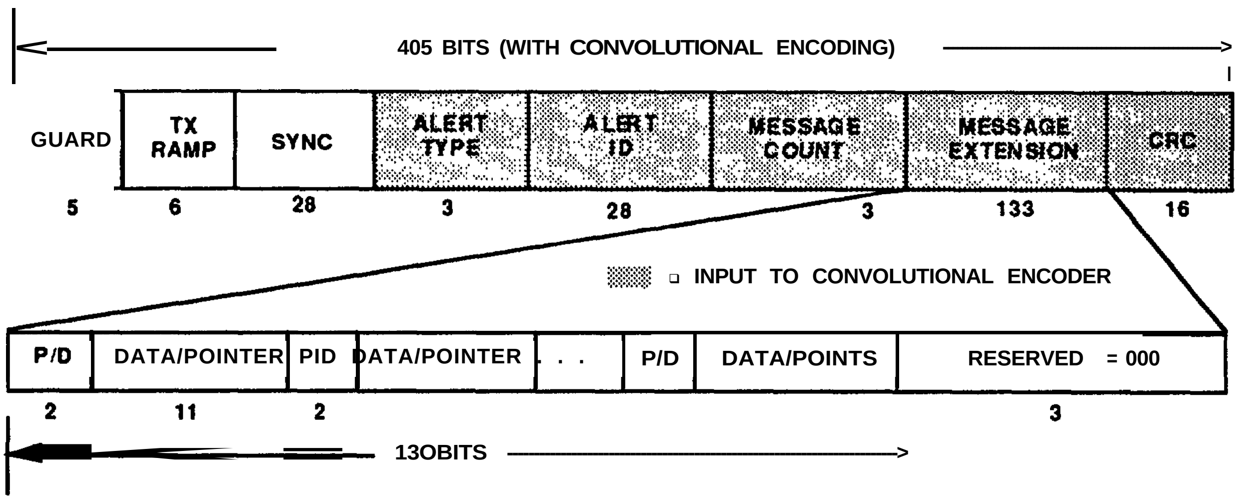


Figure 3.3.6-l Continue message structure.

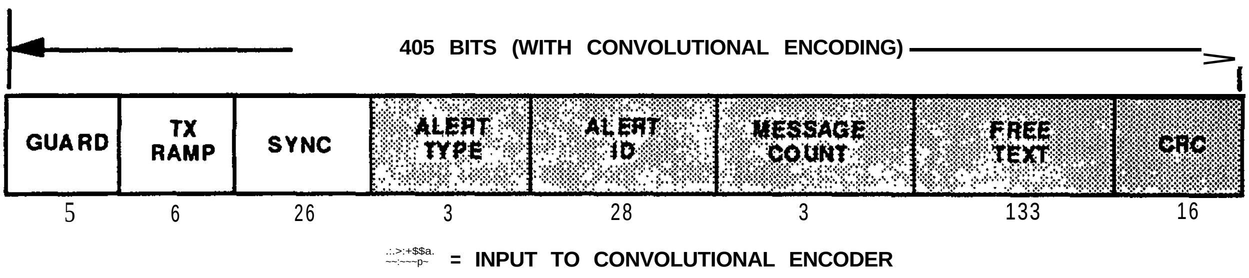


Figure 3.3.7-l Free text message structure

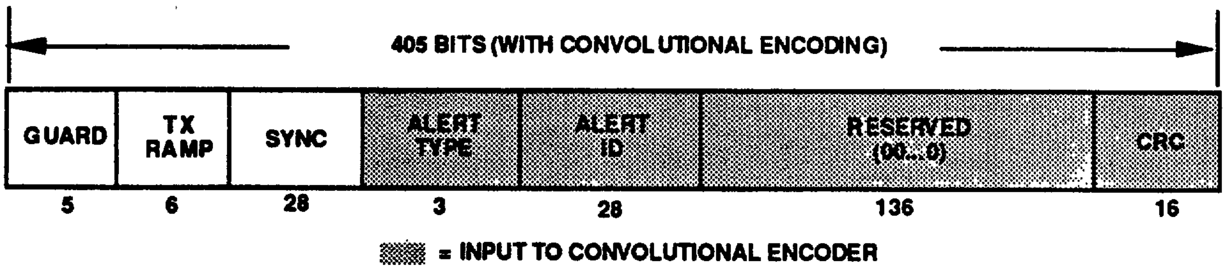


Figure 3.3.8-1 Delete message structure.

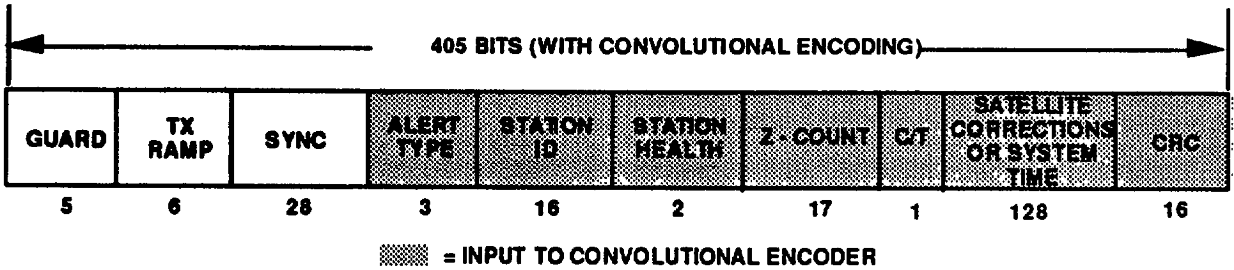


Figure 3.3.9.2-1 System time/GPS correction message structure.

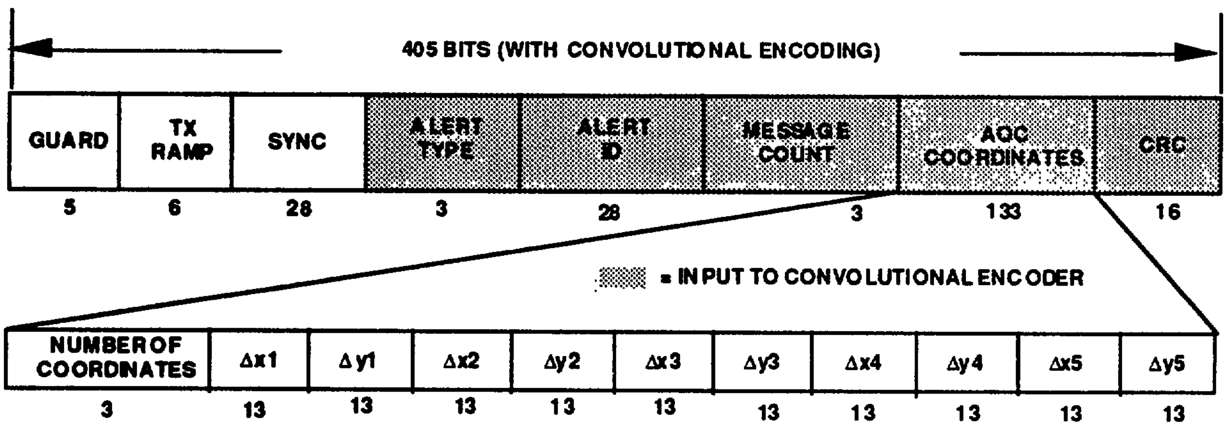


Figure 3.3.10-1 AOC extension message.

4. SYSTEM TIMING AND DIVERSITY

4.1 Base stations. Each base station shall transmit during one and only one of the six available timeslots. The available time slots shall be Slots 1 and 2 on frequencies A and B. The timeslot shall be assigned and not vary during normal system operation. The resulting four base station channels are designated Channel 1, Channel 2, Channel 3, and Channel 4. The beginning each frame shall be aligned with the once-per-second GPS time marks.

4.1.1 System time and offset broadcasts. Each base station shall transmit a system time and GPS correction message, once per second, as the first alert (ALERT 1, Figure 3.2-l) of its assigned slot.

4.1.2 Other broadcasts. The remaining four alert positions are available for basic, continue, free text, and delete message broadcasts. Base stations shall queue all messages to be broadcast into a buffer. The buffer shall be transmitted repeatedly in ALERT 2 through ALERT 5 positions. Base stations shall remove messages from the queue only upon command from the system controller.

4.2 Mobile stations Timeslot 3 reserved for transmissions by mobile stations. When activated, mobile stations shall broadcast one basic alert message every three frames. Mobile stations shall randomly select one of 30 available alert positions (2 frequencies x 5 alert positions/frequency x 3 frames) for the basic alert broadcast (slotted Aloha protocol). Mobile stations shall not broadcast delete, free text, continue, or system time and GPS correction messages. The alert ID of the mobile station basic alert message shall be pre-assigned and remain constant for all broadcasts.

APPENDIX Q:
IVSAWS WAVEFORM DESIGN #2
(RBDS COMMUNICATION WITH COVERAGE CONTROL)

This appendix describes an IVSAWS communication waveform compatible with a system architecture utilizing Radio Broadcast Data System (RBDS) communication and alert area-of-coverage (AOC) control supported by the Global Positioning System (GPS) or Position Information Navigation System (PINS).

1. WAVEFORM DEFINITION

IVSAWS System Architecture #2 uses the Radio Broadcast Data System (RBDS) to distribute hazard and advisory information to motorists. Thus, the waveform is defined by the United States RBDS Standard. The standard specifies the waveform modulation, coding, and message format.

IVSAWS uses two RBDS services, the Traffic Message Channel (TMC) and Location and Navigational Information (LN). Paragraph 1.1 summarizes the TMC service. Paragraph 1.2 defines the LN message format as applied to IVSAWS.

1.1 Traffic Message Channel RBDS group type 8A is reserved for the TMC. At the date of this Engineering Notebook (ENB), the TMC had not been defined. It is, however, expected to be similar to the European Traffic Message Coding Protocol. The protocol is sufficient to alert drivers of stationary IVSAWS hazard and advisory situations. When group type 8A is defined, a revision to this ENB will be issued which summarizes the RBDS TMC protocol.

1.2 Location and Navigation Information IVSAWS uses the LN service to identify the location of a vehicle using the Global Positioning System (GPS) or Position Information Navigation System (PINS). Type 3A groups are used to distribute data to vehicular Differential GPS (DGPS) or PINS receivers which use the information to make position calculations. The derived position is then used to compare the vehicle location to the area of alert coverage defined in a TMC alert. This process limits the dissemination of alerts to drivers who have a reasonable probability of encountering the hazard or advisory condition. Figure 1.2-1 shows the type 3A group structure.

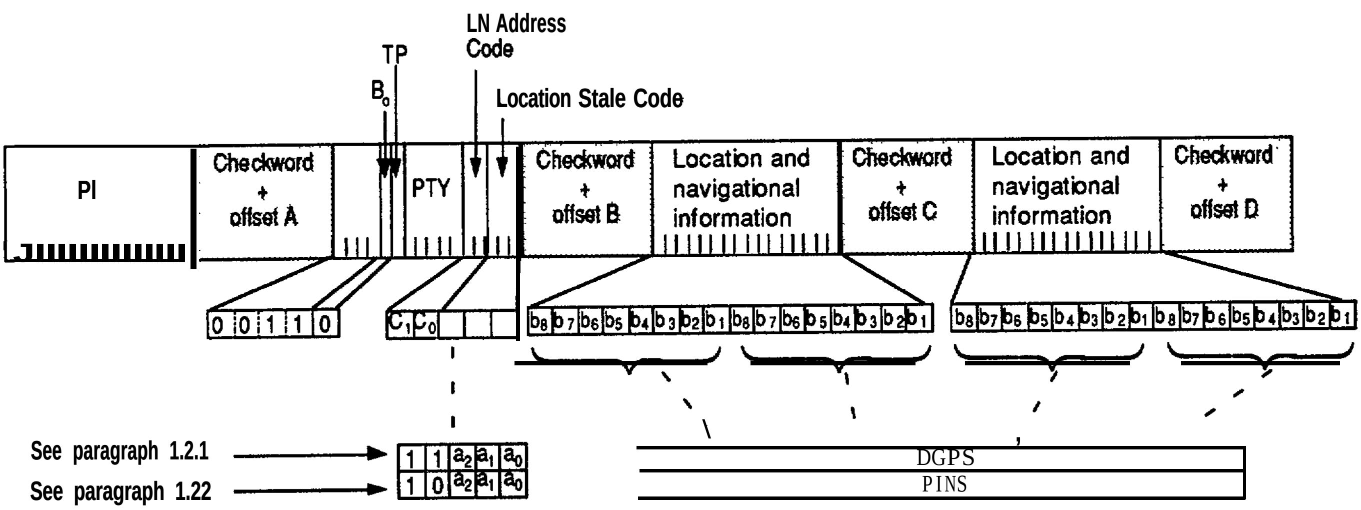


Figure 1.2- 1. Type 3A group structure

1.2.1 Differential GPS correction data Two of the eight address codes reserved for DGPS correction data (locations = 11XXX, see paragraph 3.1.3.4 of RBDS standard) are required to transfer pseudorange correction, range-rate, Z-count, and status information to vehicular GPS receivers. Table 1.2. l-l shows the required bit allocations. The type 3A group bit assignments will need to be coordinated with the National Radio Systems Committee if subsequent revisions of the RBDS standard do not include the required allocations.

Table 1.2.1-1. DGPS data

Allocation	Scale factor and units	Range	Bits
Station ID	1	1 - 16,384	14
Station health		4 states	2
Z- count	6 seconds	l-100,794 s.	17
Pseudorange correction	0.1 meters	+/- 3276.8 m	16
Range-rate correction	0.004 m/sec	+/- 0.512 m/s	8
Satellite ID	1	0-31	5
Satellite health		4 states	2
Total			64

Station ID.
calculating the pseudorange and range-rate corrections that are included in the DGPS type 3A groups.

1.2.1.2 Station health. The reference differential GPS receiver periodically compares its calculated position to its known position in order to estimate the differential data quality. The derived pseudorange correction is also examined for reasonableness. Based upon the examinations, station health is graded from 0 (poor) to 3 (excellent).

1.2.1.3 Z-count. Z-count provides vehicular GPS receivers with a coarse time reference required to achieve synchronization with the satellite signals.

1.2.1.4 Differential correction data. The pseudorange and range-rate corrections are applied to vehicular GPS receiver pseudorange and range-rate estimates prior to position calculation in order to improve the accuracy of the position estimate.

1.2.1.5 Satellite ID. Satellite ID identifies the satellite for which the corresponding differential correction data applies. The vehicular GPS receivers will discard correction data for satellites not in view. Data will also be discarded for signals originating from satellites with known poor position if a sufficient number of satellites with good position are in view.

1.2.1.6 Satellite health. Satellite health is extracted from the 50 bps GPS data stream by the reference GPS receiver. Satellite health is graded from 0 (poor) to 3 (excellent). Vehicular GPS receivers will discard correction data for satellites with fair or poor health if a sufficient number of satellites with good or excellent health are in view.

1.2.2 PINS correction data. One of the six address codes reserved for future navigation systems (locations = 10010.. 10111, see paragraph 3.1.3.4 of RBDS standard) is required to transfer commercial FM broadcast station pilot tone phase data to vehicular PINS receivers. The phase data is broadcast from a reference station which is equipped with a PINS base station subsystem. The base station subsystem measures the pilot tones of all stations within communication range and sends the data over the RBDS. For each pilot tone measured, 32 bits of information need to be broadcast. The exact format and update rate of the phase data has yet to be specified by Terrapin Corporation. Table 1.2.2-1 shows the required bit allocations. Once specified, the type 3A group bit assignments will need to be coordinated with the National Radio Systems Committee if PINS proves to be a viable IVSAWS geolocation subsystem.

Table 1.2.2-1. PINS data

Allocation	Scale factor and units	Range	Bits
Station ID			TBD
Pilot tone phase			TBD
Total			32

1.2.2.1 Station ID The station identifier specifies the frequency of the broadcast station to which the phase data applies.

1.2.2.2 Pilot tone phase Pilot tones from at least four stations (three plus the reference station) need to be measured by a vehicular PINS receiver to derive vehicle position. Pilot tone phase data is required for each station signal used in the position calculation.

APPENDIX R: IVSAWS PERFORMANCE ANALYSIS

This appendix describes the tradeoffs used to select the System Architecture Design #l (narrowband-GPS) modulation scheme for IVSAWS. Additionally, several system performance parameters for the selected modulation scheme are analyzed for rural, suburban, and urban driving environments.

Table of Contents

1. Introduction 1

2. Modulation Selection 1

3. Preamble Performance 9

4. Coverage 16

5. Forward Error Correction (FEC) Performance 29

6. Interleaver Performance 29

7. Base Station Diversity 30

8. Mobile Unit Diversity 32

9. Conclusion 33

10. References 35

GLOSSARY

AOC	Area of coverage
APSK	Amplitude-phase shift keying
ASK	Amplitude shift keying
AWGN	Additive white Gaussian noise
B	Noise bandwidth
BCH	Bose-Chaudhuri-Hocquenghem
BER	Bit error rate
BPSK	Binary phase shift keying
dB	Decibel
Ah	Terrain roughness parameter
DQPSK	Differential quaternary phase shift keying
Eb	Energy per bit
ELR	Extended Longley Rice
ERP	Effective radiated power
FCC	Federal Communications Commission
FEC	Forward error correction
FHWA	Federal Highway Administration
FM	Frequency modulation
FSK	Frequency shift keying
GPS	Global Positioning System

HAAT	Height above average terrain
HAC	Hughes Aircraft Company
IVSAWS	In-Vehicle Safety Advisory and Warning System
MER	Message error rate
MSK	Minimum shift keying
No	Noise power
Pb(e)	Probability of bit error
PINS	Position Information Navigation System
PSK	Phase shift keying
QAM	Quadrature amplitude modulation
QPSK	Quatemary phase shift keying
RF	Radio frequency
RMS	Root mean square
Rs	Channel bit rate
Rxx()	Autocorrelation function
S/I	Signal-to-interference ratio
SNR	Signal-to-noise ratio
UHF	Ultra high frequency
VHF	Very high frequency
W	Modulation bandwidth

1.0 Introduction

The IVSAWS System Architecture Analysis (Task C, Subtask 1; documented in ENB C-l-l) yielded two promising system architectures which can implement IVSAWS at different levels of cost and functionality. System Architecture #l employs a new narrowband communication link operating in the 220-222 MHz band supported by Global Positioning System (GPS) area of coverage (AOC) control. System Architecture #2 utilizes existing PM radio stations to broadcast IVSAWS alerts via the Radio Broadcast Data System (RBDS). GPS or other geolocation systems (e.g., Position Information Navigation System (PINS)) can be used to control the AOC.

This report presents the tradeoffs used to select the System Architecture #l (Narrowband-GPS) modulation scheme and analyzes several system performance parameters using the selected modulation scheme for the rural, suburban, and urban driving environments. An evaluation of System Architecture #2 (RBDS) was considered as part of this study. However, a detailed communication performance analysis of System Architecture #2 (RBDS) was deemed unnecessary for the following reasons: 1) RBDS is already designed and standardized therefore a performance analysis would be redundant, and 2) experimental results derived from field tests currently being performed under other FHWA contracts [l] will be more meaningful than estimates derived from analysis and simulation.

2.0 Modulation Selection

The system trade-offs in any digital communication system are compromises between the following parameters: 1) required bandwidth (W), 2) probability of bit error (pb(e)), 3) energy consumed per bit transmission (Eb), and 4) cost of implementation (i.e., system complexity). The System Architecture #l communication channel can be characterized as a fading narrowband channel (4 KHz) with additive white Gaussian noise (AWGN). Since bandwidth is very limited, maximization of bandwidth effkiency is a major design goal. On the other hand, minimization of required power is a lesser design goal since base station transmitters will be located at sites with plentiful power and a nationwide frequency allocation will be secured (no non-IVSAWS co-channel users). Prioritized, the design goals are as follows:

1. Maximize bandwidth efficiency
2. Minimize system cost (complexity)
3. Minimize the probability of bit errors
4. Minimize required power

Stated differently, the evaluation of the modulation scheme used to implement System Architecture #l can be based upon the four parameters R_s/W, $p_b(e)$, implementation cost, and E_b/N_o, where R_s is channel bit rate, E_b is the energy per bit, and N_o is the noise power. The first is a measure of the bandwidth required for a given source rate (bits/second per Hz), the second is a performance target, the third is a measure of system complexity, and the fourth is a measure of the power expenditure.

2.1 Bandwidth-power efficiency

Figure 2. l-l compares several modulation schemes on a bandwidth-power efficiency plane for a bit error probability $P_b(e) = 10^{-5}$ The numbers next to the symbols represent the modulation order for a given modulation scheme. The specified bit error probability is generally considered a reasonable design target for digital RF communication systems. The figure shows that ASK, PSK, MSK and APSK modulations are bandwidth efficient since they cover the region of the plane where $R_s/W > 1$. Conversely, FSK is a poor modulation selection for a bandwidth constrained system since it occupies the area of the plane where $R_s/W < 1$. It is also important to notice that for ASK, PSK, and APSK modulations, bandwidth efficiency tends to “flatten out” as the modulation order increases and ever increasing amounts of power are required to achieve an incremental improvement in bandwidth efficiency. However, for little or no additional power, substantial gains in R_s/W can be achieved as binary and quaternary systems are “upgraded” to the next higher modulation order. Note in particular that QPSK has twice the bandwidth efficiency as BPSK at the same energy (E_b) cost.

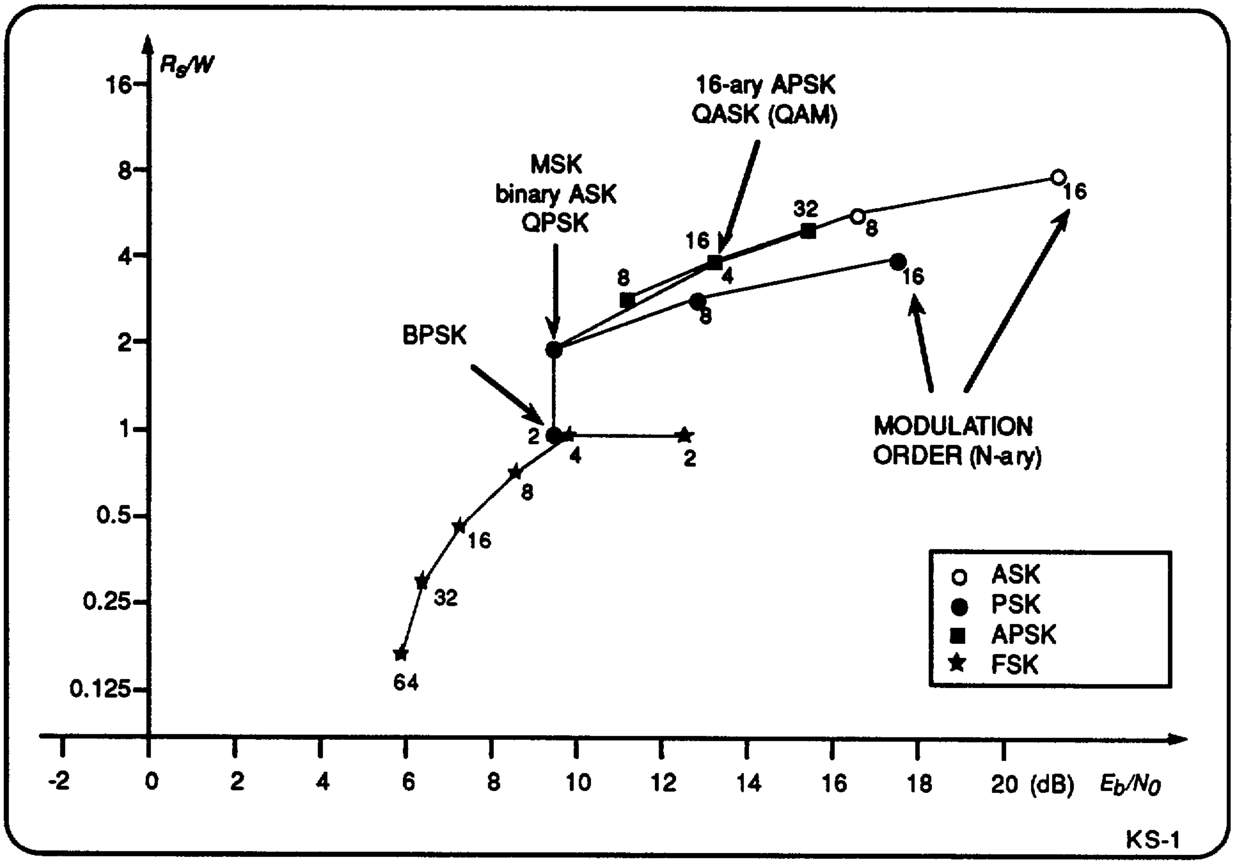


Figure 2.1-1 Bandwidth-power efficiency plane (coherent demodulation, Pb(e) = 10^{-5})[2].

Ignoring system complexity, it is evident that binary ASK, QPSK, and MSK are prime modulations scheme candidates if bandwidth and power efficiencies are to be maximized simultaneously. Noting that System Architecture #1 places a premium on bandwidth efficiency, it can be argued that 8-ary APSK, 16-ary APSK, and 4-ary ASK (QAM) are also good candidates.

2.2 System complexity (cost)

Figure 2.2-1 shows the relative complexity of different modulation schemes. FSK is a very cost effective modulation scheme when noncoherent detection is used. Conversely, the complexity of APSK receivers place the APSK waveforms at a cost disadvantage with respect to ASK, QPSK, and MSK waveforms. Also shown are the relative complexity of differentially encoded QPSK and differentially encoded MSK waveforms. Differentially encoded waveforms can substantially reduce system complexity since no coherent carrier recovery is required (however, additional Eb is required to maintain the same $P_b(e)$, ~ 2 dB for QPSK and MSK). Differentially encoded MSK and QPSK modulation schemes are of similar complexity.

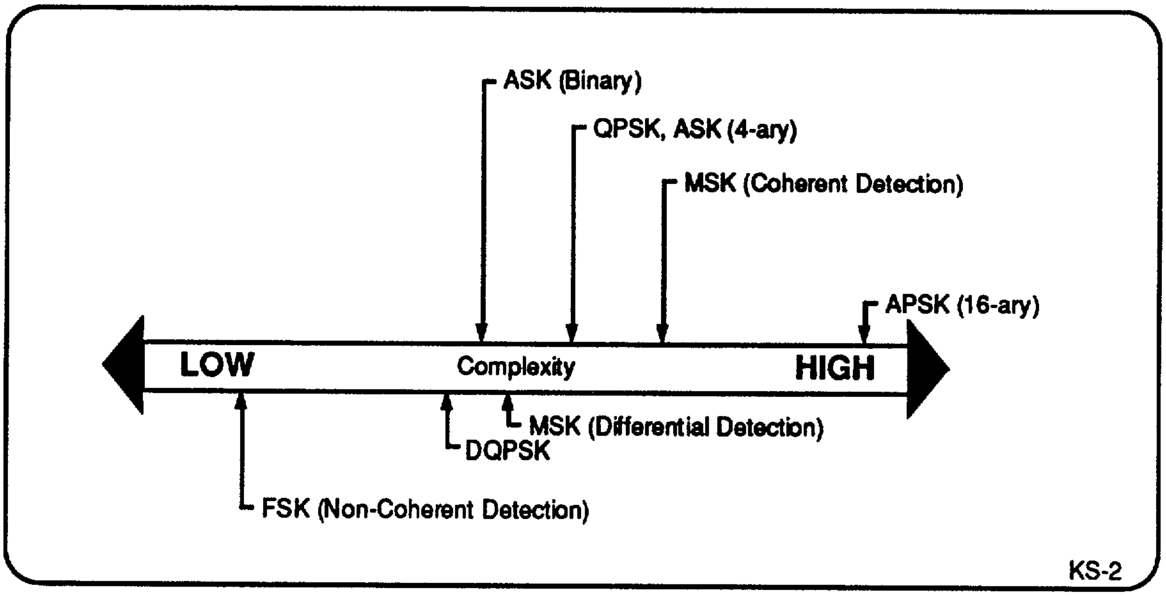


Figure 2.2-1 Relative complexity of candidate modulation schemes.[3]

The use of higher order ASK modulations will have a significant impact on transmitter complexity if, as expected, high power amplifiers are used to transmit the waveform. The out-of-band spurs introduced by amplifier non-linearities are more difficult (and expensive) to reject as peak-to-average power and transmitter gain increase. For example, the peak-to-average power of 4-ary ASK is 2.6 dB whereas elements of PSK signal sets are equal energy.

2.3 Performance in the presence of impulsive noise.

Field tests have shown that impulsive environmental (natural) noise is not a significant contributor to the composite environmental noise profile at frequencies above 100 MHz[4]. The channel noise can be characterized as AWGN in the 220 - 222 MHz band. However, impulsive noise from man-made sources could corrupt individual symbols if the noise pulse width is long enough (> 100 microseconds). The most significant source of impulsive noise will be automobile ignition systems which are in close proximity to the vehicular IVSAWS receivers. Data was obtained from General Motors on the RF characteristics of engine ignition noise. Each spark plug firing produces a 2 microsecond noise burst. This is substantially less than a bit period for links supporting data rates on the order of 5 - 10 kbps and therefore the effects of impulsive ignition noise on $P_b(e)$ can be ignored. For IVSAWS, the AWGN channel model is a better model than an impulsive noise channel model.

2.4 Performance in the presence of Rayleigh fading.

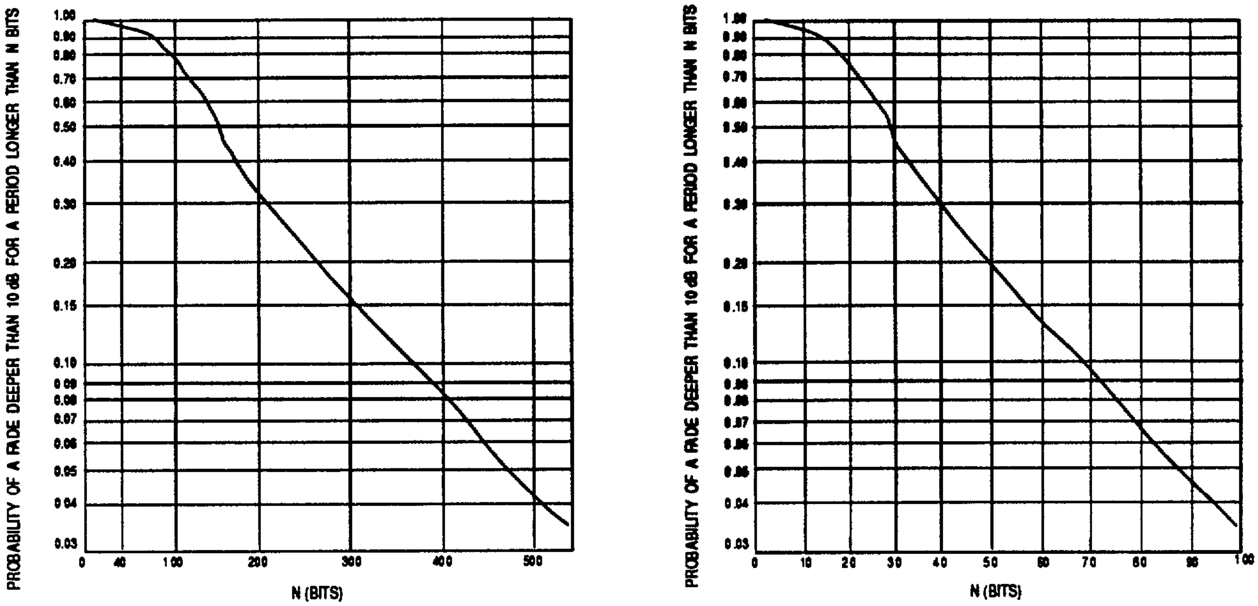
In the IVSAWS environment, radio waves will reflect off many sources including hills, roads, aircraft and buildings. The primary effect of the reflections is the introduction of multipath fading. Having nondirect wave components at reception, a case of Rayleigh fading, is the worst type of fade in the mobile communication environment. If the amplitudes of the reflected signals are nearly equal, a deep fade will occur and communication will be effectively blocked. The effect of Rayleigh fading is most pronounced in environments with a large number of reflectors (e.g., a city street packed with cars). With respect to the IVSAWS communication environment, Rayleigh fading will be most pronounced 1) in urban areas, where tall buildings block a direct signal path from a base station transmitter and 2) during mobile broadcasts; due to low transmitter and receiver antenna elevation, blockage of the direct path between mobile IVSAWS transmitters and receivers can occur in all environments (urban, suburban, and rural).

The Rayleigh cumulative probability distribution function given by

$$P(r \leq R) = 1 - \exp(R^2/\overline{r^2}) \qquad (2.4.1)$$

where r is the envelope of the fading signal, $\overline{r^2}$ is the average power of the fading signal, and R is the amplitude variation with respect to its rms value ($\overline{r^2}^{\,1/2}$), $R = (r^2/\overline{r^2})^{1/2}$.

If the duration of a deep fade is sufficiently long, a string of bits will be "erased" from the bit stream, introducing a burst error. The use of interleavers and forward error correction (FEC) can be used to reduce to impact of burst errors. IVSAWS interleaver and FEC design are discussed in Sections 5 and 6. Analysis and experimentation has shown that at vehicle (receiver) speeds between 15 mph and 80 mph the average duration of a fade 10 dB below the RMS signal level will range from 32 milliseconds to 6 milliseconds, respectively [5]. When the received IVSAWS signal power is near the receiver's sensitivity (e.g., when the receiver is just within communication range), the corresponding burst errors will range from 194 to 36 bits in duration. Figure 2.4-1 shows the probability of a fade occurring at level deeper than 10 dB below its rms value for a period greater than N bits.



(a) Vehicle speed = 15 mph

(b) Vehicle speed = 80 mph

Figure 2.4-1. Rayleigh fading probability at 220 MHz.

The size of the fading region is proportional to wavelength. Also, vehicles travelling at higher speeds will move through the fading region more quickly, reducing the average fade duration. However, fades will occur more often at higher speeds.

Table 2.4-1 lists the performance of several modulation schemes on Rayleigh fading channel. As can be seen, differential QPSK modulation requires twice as much bit energy to achieve the same performance as MSK, binary ASK, and 4-ary ASK modulations.

Table 2.4-1 Performance of candidate modulation schemes over a Rayleigh fading channel [6].

Modulation scheme[1]	Average Eb/No (dB) required for $P_b(e) = 10^{-2}$
Binary ASK	17
4-ary ASK	17
MSK	17
QPSK	20

[1]differentially coherent demodulation

2.5 Rician fading environment.

Rician fading occurs when direct and nondirect wave components combine at reception. Rician fading will dominate Rayleigh fading in the suburban and rural IVSAWS communication environment provided base station transmitters are elevated and a direct path exists between the transmitter and vehicular receivers. As mentioned previously, Rayleigh fading can be expected over the mobile-to-mobile IVSAWS channel, even in rural areas.

The Rician cumulative probability distribution function is given by

$$P(r \leq R) = \int_0^{R_0} r_0 \exp\left(\frac{-r_0^2 + a_0^2}{2}\right) I_0(a_0 r_0)\, dr_0 \qquad (2.5.1)$$

where r and R are as defined in equation 2.4.1, $I_0(\,)$ is the modified Bessel function of zero order, a is the amplitude of the direct wave, and R_0, a_0, and r_0 are normalized parameters defined below as

$$R_0 = R/(\overline{r^2}/2)^{1/2}, \quad a_0 = a/(\overline{r^2}/2)^{1/2}, \quad \text{and} \quad r_0 = r/(\overline{r^2}/2)^{1/2}.$$

When the ratio of the amplitude of the direct signal to the rms amplitude of the composite signal ($a_0/\sqrt{2}$) is 1.5 dB, the probability that the received signal level is 6 dB below the rms signal level is 0.01. Comparatively, from equation 2.4.1, the probability of a fade of the same depth over a Rayleigh fading channel is 0.23. Rician fades will be of shorter duration and less frequent than Rayleigh fades of equal depth.

2.6 Final Modulation Scheme Selection.

Since bandwidth efficiency is the primary modulation scheme design goal, FSK modulations were eliminated as candidates for the IVSAWS since they are bandwidth inefficient relative to PSK, MSK, and ASK waveforms. ASK, APSK and high-order (> 4-ary) PSK modulations were rejected due to implementation complexity (cost). After this process of elimination, tradeoffs were performed between BPSK, QPSK, and MSK modulations. Though more complex, QPSK has twice the bandwidth-power efficiency as BPSK. Thus, BPSK was eliminated, again due to the premium place on bandwidth efficiency. Finally, QPSK and MSK were compared.

MSK and QPSK occupy the same point on the bandwidth-efficiency plane. When differentially coherent demodulation is used to reduce receiver complexity, MSK and QPSK modulations are also of similar complexity (cost). Evidence suggests that MSK has slightly better performance (~ 3 dB) than QPSK over a Rayleigh fading channel (see Table 2.4-1). On the other hand, DQPSK has been adopted as the standard for the emerging United States digital cellular telephone system. Other American digital radio systems such as RBDS appear to be favoring QPSK modulation schemes. Thus, parts and test equipment availability may place a QPSK-based IVSAWS at a slight cost advantage with respect to a system using MSK. In short, MSK has a slight performance advantage while QPSK has a slight cost advantage. Cost was considered to be the dominant factor and DQPSK was selected as the modulation scheme for the IVSAWS system architecture #1.

2.6.1 π/4-Shifted DQPSK.

Modifications can be made to the DQPSK waveform in order to improve its bandwidth efficiency and reduce the cost of implementation. Raised-cosine filtering the in-phase and quadrature channels suppresses sidelobes and shapes the main lobe such that higher data rates (relative to unfiltered DQPSK) can be achieved while maintaining conformance to 220 - 222 MHz band spectral emissions requirements. Assuming perfect symbol synchronization, raised cosine filtering will not generate intersymbol interference (ISI). Even without ISI, performance degradation does occur since 1) the higher data rate reduces the energy per bit (assuming fixed ERP) and 2) pulse energy from the unfiltered full response baseband waveform is diverted to construction of the partial response baseband waveform "tails" which smooth the bit transitions and enhance spectral containment. The effect can be modelled as a reduction in E_b.

Secondly, offsetting, or shifting, the I and Q channels by one symbol period creates a more uniform envelope with respect to QPSK (without performance degradation) thereby enabling the use of lower cost RF amplifiers.

Figure 2.6.1-1 shows the simulated performance of the IVSAWS π/4-shifted DQPSK waveform over a static (non-fading) channel corrupted by AWGN. No equalization, FEC, or interleaving was applied. The model was constructed on Hughes' Signal Processing Workstation. The purpose of the simulation was to determine the effects of baseband filtering on bit error rate performance with respect to theoretical unfiltered DQPSK (differentially coherent demodulation). All simulation points fell within a ± 0.5 dB envelope of the unfiltered DQPSK performance. It appears baseband filtering has minimal effect on BER performance.

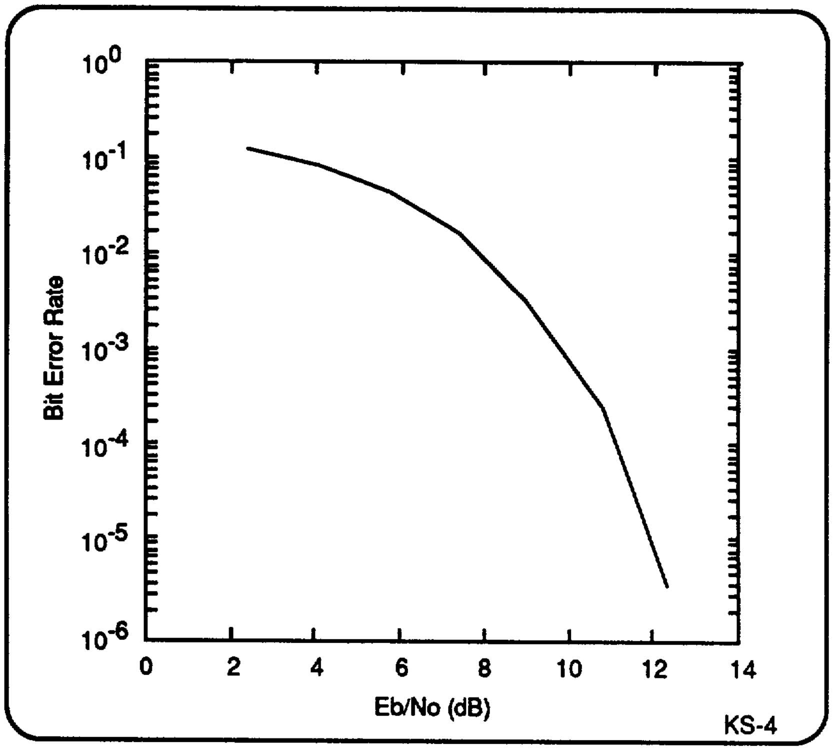


Figure 2.6-1. IVSAWS π/4-shifted DQPSK performance (differentially-coherent demodulation).

3.0 Preamble design and performance.

The primary function of the communication architecture is the reliable delivery of hazard warnings and alert messages. This notification process is facilitated by reliable digital communication from the IVSAWS operations center to the many motorist and deployment community vehicles. In order to demodulate the message data, the receiver must first detect the presence of the signal and acquire the message timing. The preamble is a special pattern placed at the beginning of each message to enable the receiver to detect the presence of a message. Preamble detectability in the presence of noise is balanced to the error correction protection of the message data.

Preamble design considers of overall length, symbol selection, and performance in the presence of noise. Preamble length is a tradeoff between enhancing detectability at the cost of increased receiver complexity. Preamble symbols are selected to maximize autocorrelation functions so that delayed versions of the same signal in a multi-path environment do no confuse the receiver. The performance in the presence of noise is measured both by the probability of detection and the probability of false alarm. The probability of detection and false alarm are interrelated and depend on both the length of the preamble and the signal to noise ratio at the selected operating point.

3.1 Preamble length.

An important consideration in determining the appropriate preamble length is the potential use of the preamble to train an adaptive equalizer. Adaptive equalization can reduce the probability of bit errors over land mobile (Rayleigh fading) channels. When used for adaptive equalization, the preamble has an optimum length which represents a trade-off between wasting bandwidth in unnecessary training symbols and providing enough symbols for good channel impulse response estimation.

Several types of adaptive equalizers are candidates for implementation. However, implementation of an equalizer will not be required or recommended in the system description document. Rather, a waveform has been designed which can support several equalizers which use a known data sequence for training. Equalizers examined include 1) tap delay line (TDL), 2) decision feedback equalization (DFE), and 3) lattice equalizers.

Research indicates that between 5 percent and 10 percent of the available bandwidth should be reserved for equalizer training in fast flat Rayleigh fading channels in which the ratio of Doppler spread to the symbol rate (f_d/f_s) is below 0.05 (corresponding to a vehicle travelling under 125 mph, f_s = 3037.5 symbols/sec)[7]. A twenty-eight bit (14 symbol) preamble was selected which consumes seven percent of the available bandwidth.

3.2 Autocorrelation function.

The preamble selected corresponds to the following sequence of baseband phase <u>changes</u>:
$-\pi/4$ $-\pi/4$ $-\pi/4$ $3\pi/4$ $\pi/4$ $3\pi/4$ $-3\pi/4$ $3\pi/4$ $-3\pi/4$ $-\pi/4$ $3\pi/4$ $\pi/4$ $-\pi/4$ $-\pi/4$.
A polar plot of the preamble autocorrelation function, $R_{xx}(\tau)$, is shown in figure 3.2-1. As can be seen from the figure, the magnitude of the function is near zero at time shifts within ±3 symbols of $\tau = 0$. Thus, if the IVSAWS receiver clock does not drift more than 3 symbols (~ 1 millisecond) between message receptions, a low probability of false alarm and high probability of synchronization can be maintained since an optimized threshold can be selected due to good autocorrelation character near $\tau = 0$. The GPS subsystem embedded into System Architecture #1 provides a once per second time mark accurate to within +/- 100 nanoseconds, and will therefore provide an excellent time reference. A receiver clock accurate to within 10 parts per million could also be used as a time reference provided messages are received at least once every 100 seconds. Such a clock could also be used maintain system time during periods in which the GPS signal

"drops out" due to blockage or multipath. Completely asynchronous signal acquisition is of course possible, however, the phase between the received signal and synchronization sequence will need to be monitored in order to assure proper time alignment since the autocorrelation function magnitude is unity at three points.

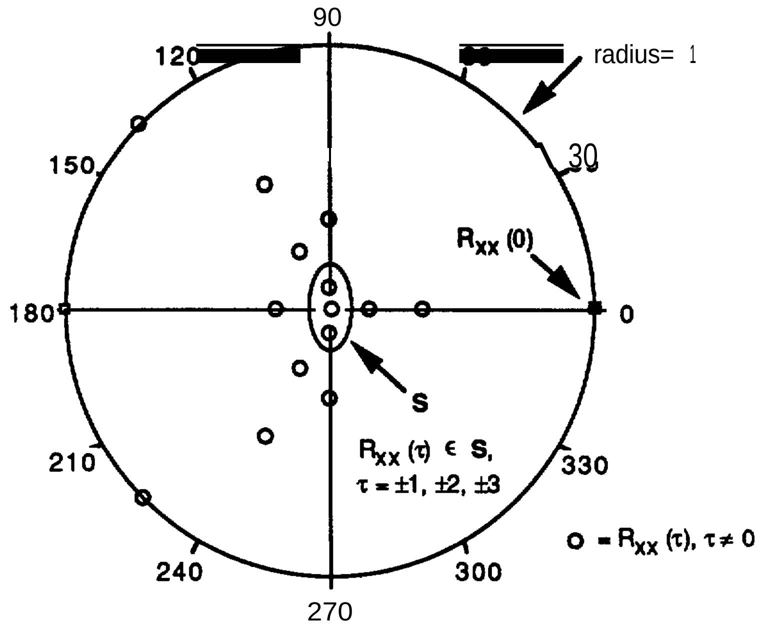


Figure 3.2-1 IVSAWS preamble autocorrelation function.

3.3 Probability of detection and Probability of false alarm.

Preamble design consists of balancing the "strength" of the preamble to the "strength" of the message data The special preamble pattern is detected using a correlator. The correlator is essentially measuring the presence of energy. When sufficient energy is detected, the correlator declares the presence of a message and then other portions of the receiver demodulate the data. A long preambles makes it easier for the correlator to detect the preamble. However, the correlator and synchronization circuitry are the most expensive portions of any digital receiver. For cost reasons, the preamble should be as short as possible. The tradeoff between long and short is relative to the message data.. If the preamble is stronger than the message data, then the receiver can detect the preamble but can't demodulate the message data. If the preamble is weaker than the message data, then the receiver doesn't detect the presence of a message even though the receiver could demodulate the data. For a safety system, such as IVSAWS, the preamble length may be increased beyond this minimum length in order to provide sufficient guarantee that reliable message detection always occurs. The following analysis shows the selected 14 symbol preamble achieves a worse case performance (at the minimum signal levels) equivalent to a probability of detection of 99 percent with a false alarm rate that is less than one in one hundred thousand opportunities. At signal strengths better than the absolute minimum, the probability of detection is significantly increased and the probability of false alarm is significantly decreased.

In digital communication systems, standard operating points for voice is 10^{-3} bit error rate and for data is 10^{-5} bit error rate. As a safety system, a 10^{-6} bit error rate for an operating point is a more stringent design point. As discussed in subsequent sections, at this 10^{-6} bit error rate operating point, the required signal level, Eb/No, for proper demodulation is 12.5 dB for the QPSK modulation. Furthermore, with the selected half rate convolutional code combined with the QPSK modulation, at this 10^{-6} bit error rate operating point, the required signal level, Eb/No, for proper demodulation is 7.0 dB. Thus the coding gain between the coded and uncoded data is 5.5 dB. If the signal strength is greater than 7.0 dB, then the error rate in the data will be significantly less, thus assuring error free transmission. The preamble to data balance computation uses this worse case operating point to determine the minimum guaranteed performance.

The information for determining preamble performance comes from the design of radar signals which is strictly an energy detection problem. Table 3.3-1 lists the preamble calculations. Table 3.3-1 shows that several factors are combined to determine the effective preamble signal to noise ratio. The probability of detection and probability of false alarm are then functions of this effective signal to noise ratio. Generally, the desired probability of detection is specified and then the associated probability of false alarm is ascertained from available graphs.

The minimum threshold that the digital data is demodulated is at 7.0 dB and hence the preamble pulses in the message will also be at this signal strength. To detect the presence of such a message, the energy in preamble pulses are combined to produce the effect of one "high energy" pulse that would be easily detected. The designed preamble has a length of 14 symbols, which is 11.46 dB in length. Combining 14 pulses to create the effect of one strong pulse is a losses process. From Figure 3.3-1, combining 10 to 25 pulses at 7.0 dB signal to noise ration results in 3 to 4 dB of losses. Also since preamble timing is not yet refined, pulse sampling can be off the peaks by nearly half power, so 2.0 dB of timing losses is also budgeted. Hence the resulting energy differential that the preamble length provides after implementation losses is 6.46 dB. This preamble energy differential is combined with the demodulation threshold of 7.0 dB to produce the effective preamble signal level of 13.46 dB.

11.46 dB	Preamble length	6.46 dB	Differential
- 3.00 dB	Nonlinear combining losses	7.00 dB	Data SNR
-2.00 dB	Timing losses	13.46 dB	Preamble SNR
6.46 dB	Differential		

Figure 3.3-2 presents the probability of detection and probability of false alarm as a function of the effective preamble signal level. The communication system must be robust so that messages are not missed. An appropriate preamble operating point for robustness is that the probability of detection is 0.99. With a 13.46 dB signal level and 0.99 probability of detection, the resulting probability of false alarm is 10^{-5}, which represents at most one false alarm in one hundred thousand reception opportunities. Such false signals are then rejected by the error correction and detection codes in the message signal processing.

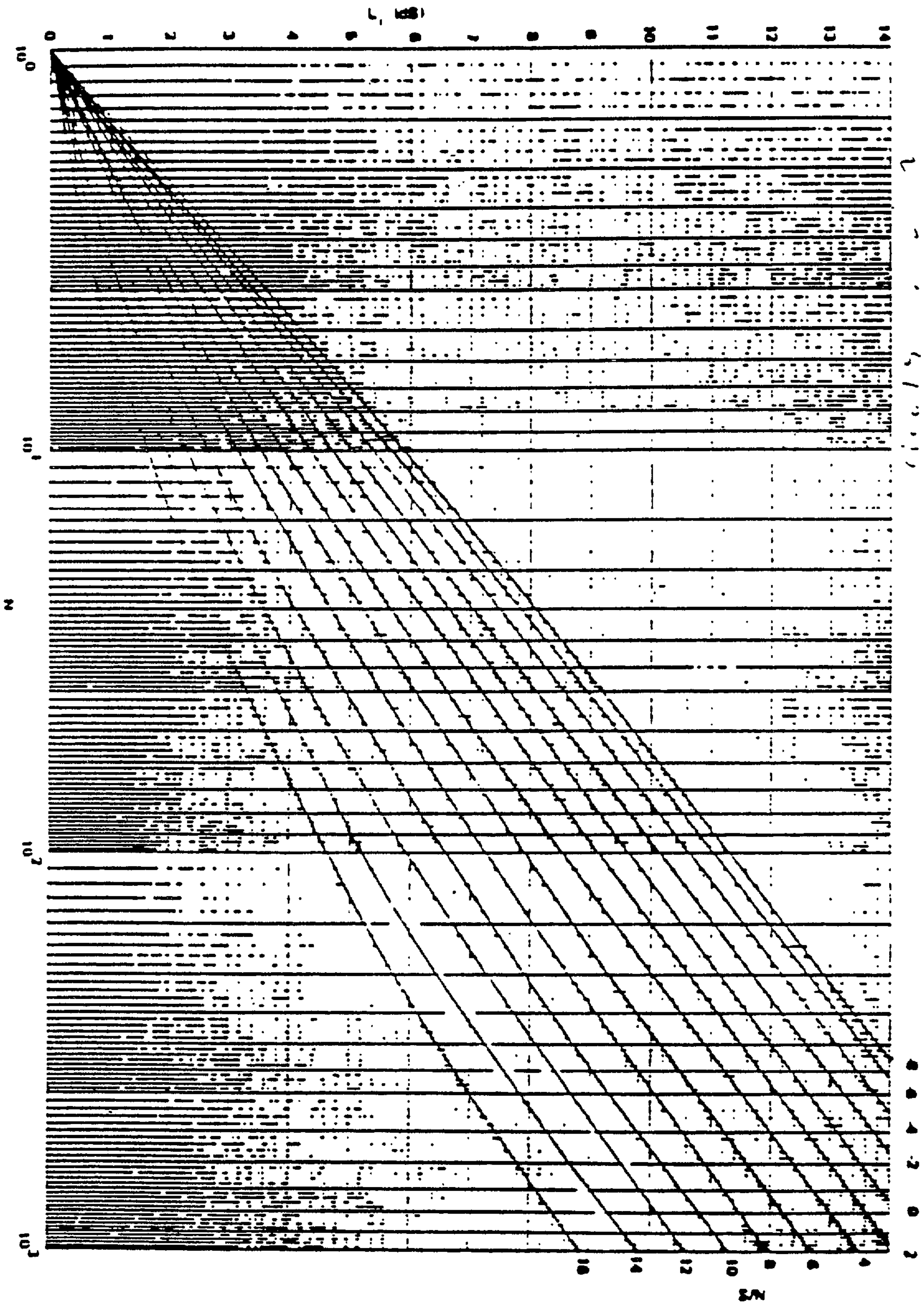


Figure 3.3-1 Nonlinear combining Losses. Noncoherent combining losses as a function of the number of pulses combined and the per pulse signal to noise ratio.

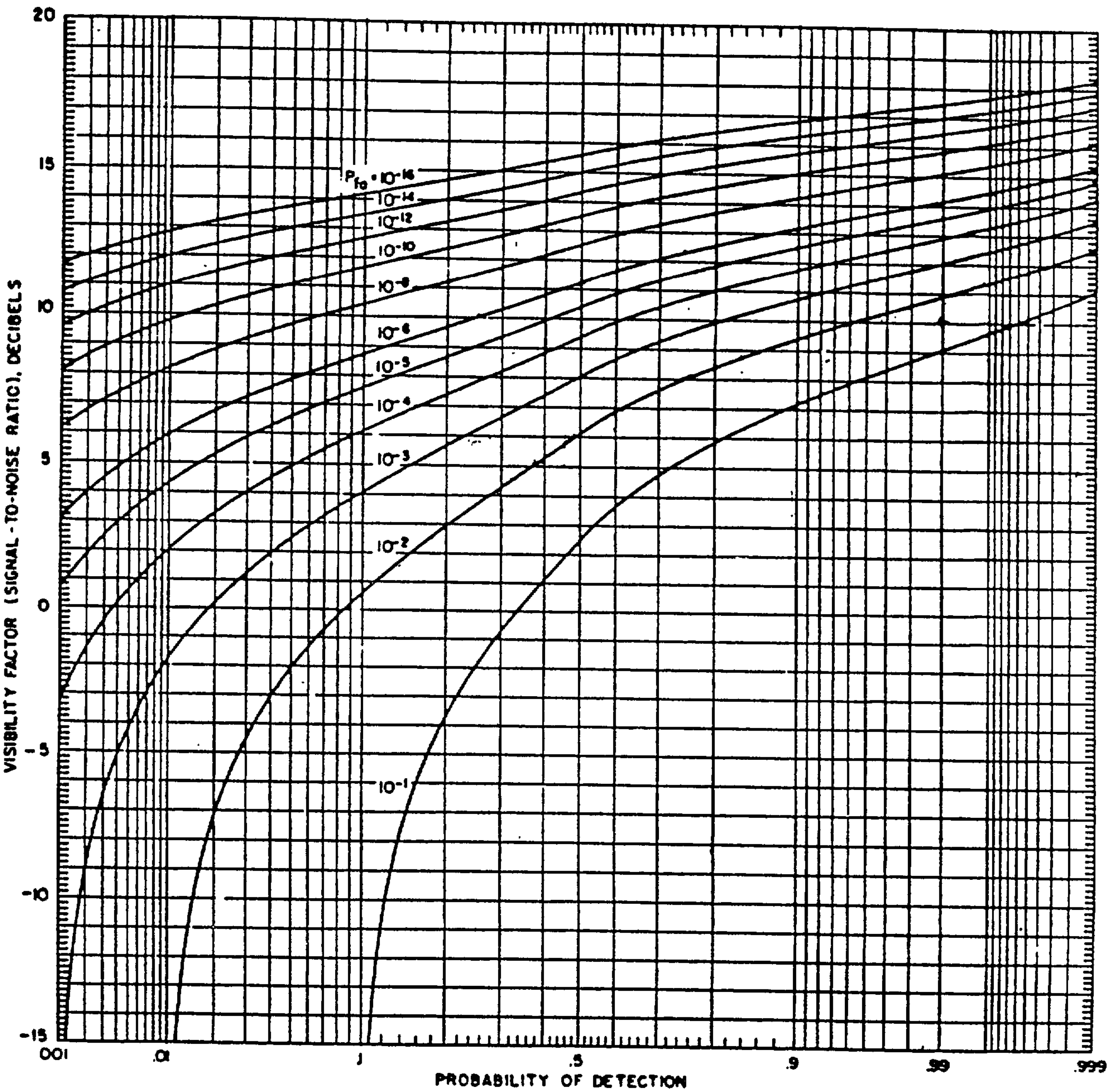


Figure 3.3-2. Detection and False Alarm Performance. Required signal to noise ratio as a function of probability of detection to achieve a particular probability of false alarm.

4.0 Coverage.

The coverage of the base station transmissions will have a significant impact on IVSAWS infrastructure cost. If base station-vehicular receiver links can be maintained over longer distances, the density of base stations can be reduced. Figure 7-1 shows that, over flat terrain, extending the communication range by a factor of 2.5 will reduce the required base station density by a factor of seven. Since IVSAWS is focused on the vast rural transportation environment, significant savings can be achieved by extending the IVSAWS communication range.

Coverage is a lesser issue with respect to transmissions from mobile units. The original IVSAWS Task C report showed that a driver alert distance of 1.2 kilometers is sufficient for drivers to detect and understand the IVSAWS alert, select and initiate a warning response, and complete the hazard avoidance maneuver (heavy truck travelling at 80 mph, full stop required). Thus, a 1.2 kilometer communication range is sufficient for mobile broadcasts. Since mobile transmitters use a Slotted ALOHA time-division multiple-access (TDMA) protocol, coverage that significantly exceeds this range is undesirable since mobile transmitters located far from a given vehicular receiver will compete for time slots with nearby mobile units which pose a real hazard to the driver. Mobile unit throughput is examined in Section 8.

IVSAWS communication range is a function of 1) transmitter power, 2) receiver sensitivity, 3) demodulation threshold (Eb/N0) required for a specified performance (BER) 4) noise level at the receiver, and 5) path loss, including the effects of fading.

4.1 Transmitter Power.

In the 220 - 222 MHz band, the effective radiated power (ERR) for base stations is limited to 500 Watts for antenna heights above average terrain (HAAT) up to 150 meters. The allowed ERP decreases for HAATs greater than 150 meters. Above 1050 meters, the maximum ERP is 5 Watts. These power restrictions will not permit an affordable IVSAWS implementation due to the number of base stations that would be required to provide adequate rural coverage. However, since IVSAWS will operate without co-channel users (nationwide frequency allocation), it is anticipated that an exemption to the restrictions can be secured provided out-of-band emissions do not exceed the limits specified in the FCC rules using the specified ERP limits. The communication range analysis made herein assumes a base station ERP of 500 Watts <u>at all antenna heights</u>

Mobile IVSAWS transmitters are restricted to an ERP less than or equal to 50 Watts.

4.2 Receiver sensitivity.

With an input signal power of -110 dBm (direct coupling), the in-vehicle IVSAWS receivers are assumed to maintain a BER of 1 x 10^{-5} without FEC.

4.3 Demodulation threshold (Eb/N0).

In order for the soft decision Viterbi decoder used in the IVSAWS receiver to operate effectively, the BER before the decoder needs to be below 5 x 10^{-2}. Figure 4.3-l shows the output BER as a function of the channel (input) BER for a hard decision Viterbi decoder. In order to maintain an output BER of 1 x 10^{-5} (MER = 4 x 10^{-3}), the channel BER must be less than 2.5 x 10^{-2}. Figure 4.3-2 shows channel BER as a function of E_b/N_0 over a Rayleigh fading channel using DQPSK. An E_b/N_0 of 13 dB is required to maintain a 2.5 x 10^{-2} channel BER. An eight-level soft decision decoder requires 2 dB less energy per bit to maintain the same BER[8] Thus, the required demodulation threshold over a Rayleigh fading channel using 3-bit soft decision Viterbi decoding is 11 dB.

Stated differently, over a Rayleigh fading channel, the demodulation of a DQPSK waveform received at a level 11 dB above the noise floor will produce a channel BER of -3.5 x 10^{-2}. A 3-bit soft decision Viterbi decoder will then reduce the BER to 1 x

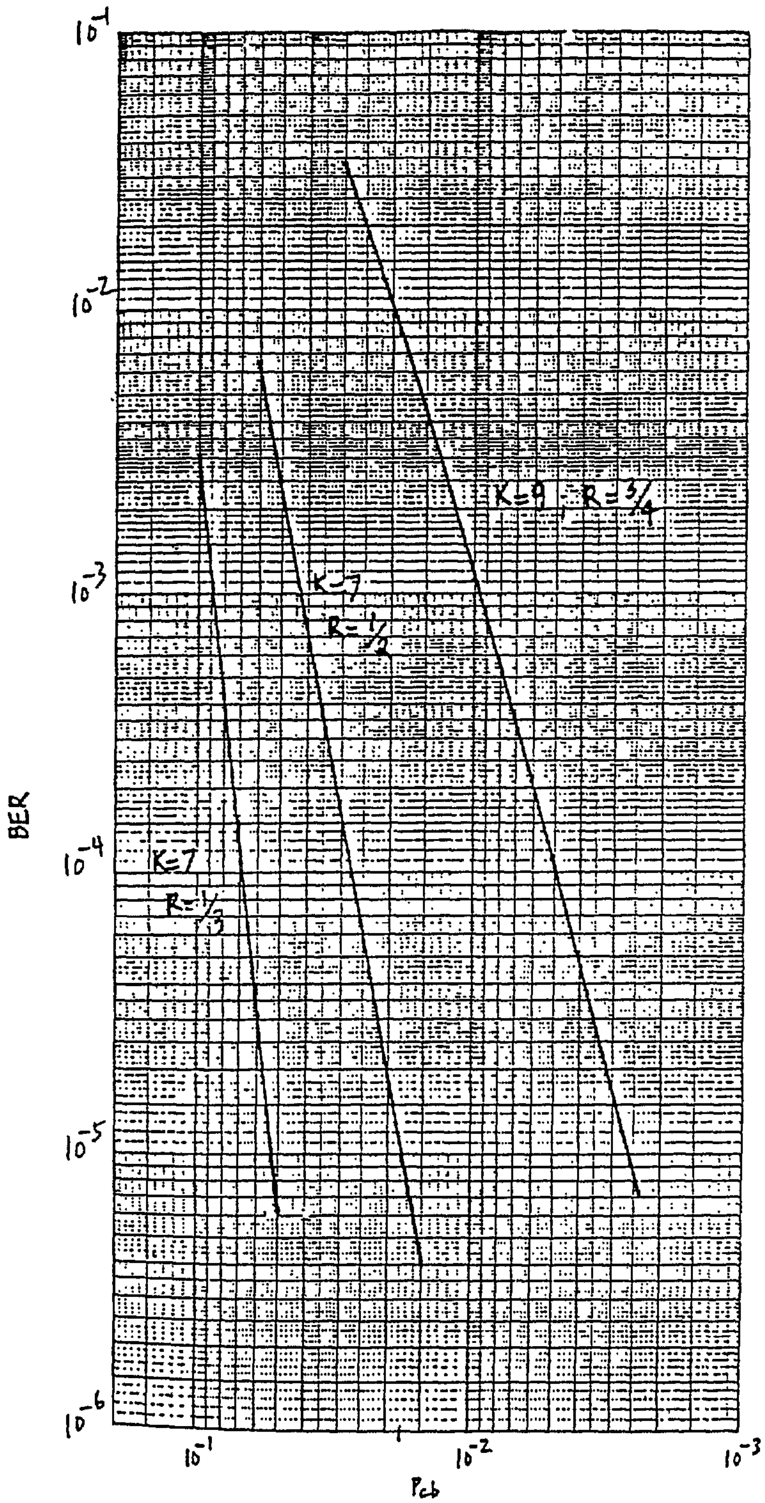


Figure 4.3-1. Relationship between average channel bit error rate (Pcb) and the BER at the output of a hard decision Viterbi decoder (K = constraint length, R = code rate).

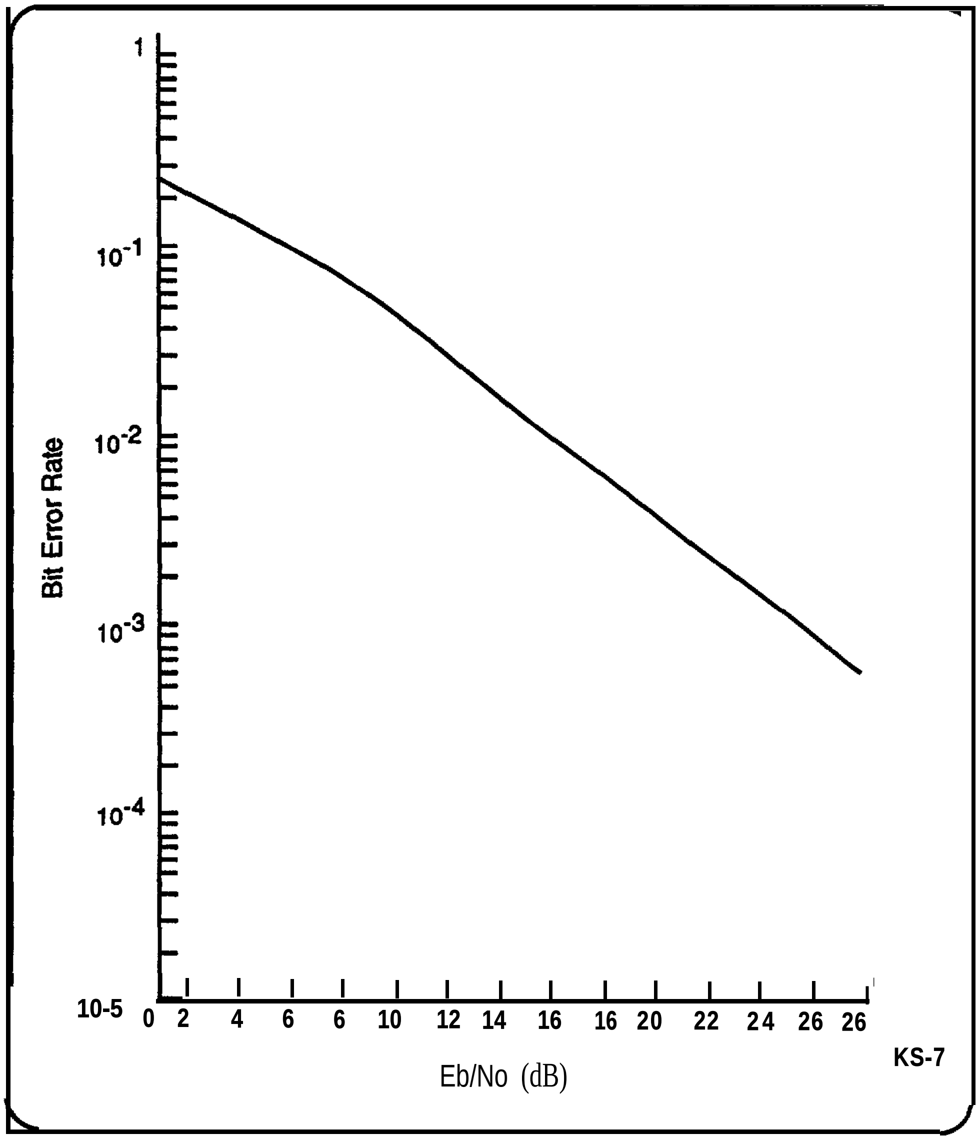


Figure 4.3-2. DOPSK BER performance over a Ravleieh fading: channel.

4.4 Noise level.

At 220 Mhz, ignition noise will dominate other sources of natural and environmental noise[8]. Vehicular NSAWS radios will receive noise from the vehicle in which it is installed and from ignition systems of nearby vehicles. The composite noise level is a function of the traffic density. Table 4.4-l lists the noise level above kT_0B for various traffic flows. One hundred cars per hour is considered light traffic and will be used as a baseline for the rural transportation environment.

The urban and suburban noise levels will be based upon a traffic flow of 1000 and 500 cars per hour, respectively.

Table 4.4-l. Noise power at receiver.

Environment	Traffic flow (cars/hour)	Noise level above kToB (dB)	Noise power at receiver (dBm)
rural	100	20	118
suburban	500	28	-110
urban	1000	35	-103

The noise power at the receiver was calculated by summing each member of the third column with a calculated kT_0B The thermal noise at room temperature (T_0 = 290 ^{0}K) with an IVSAWS receiver noise bandwidth of 4 kHz is about -138 dBm. The different noise levels show that higher received signal levels are required to maintain the same BER performance in urban environments. Since IVSAWS base station ERP is limited, noise alone will reduce urban IVSAWS communication range with respect to suburban and rural deployments. The received signal power (Pr) required to obtain an 11 dB Eb/No can be derived by

$$SNR = Pr/(NoB) = (Eb/No)(R/B) = 1l dB + 10 \log (R/B) = 11 \text{ dB} + 10 \log (6075/4000) = 13 \text{ dB}$$

where R is the bit rate and B is the receiver noise bandwidth. Thus,

$$Pr(\text{threshold}) = 13 \text{ dB} + N_0B = \begin{cases} -90 \text{ dBm (urban)} \\ -97 \text{ dBm (suburban)} \\ -105 \text{ dBm (rural)} \end{cases}$$

Substantially higher received signal power is required to maintain performance in the urban environment. Since base station and mobile transmitter transmit power limits are geographically uniform (no exception for transmitters in urban areas), the effect of urban noise will be reduced communication range with respect to ranges achievable in rural and suburban environments. Thus, higher urban base station density is required to provide uninterrupted communication coverage.

4.5 Path loss.

The Hughes Aircraft Company Extended Langley-Rice (ELR) model was used to calculate path loss and the resulting communication range over a set of candidate IVSAWS communication links.

The purpose of the ELR model is to provide a means of computing propagation attenuation based on the siting of transmitting and receiving units. It combines the propagation attenuations attributable to (1) terrain irregularity, (2) free space, (3) vegetation, and (4) climate. The Extended Longley-Rice (ELR) model is useful in the frequency range of 20-20,000 MHz. There are two modes. The point-to-point mode is extremely detailed, and incorporates terrain and foliage information for simulation of propagation attenuation along specific paths. The area mode requires less detailed data input, does not account for foliage losses, and provides a statistical representation of expected propagation attenuation. The area mode was used to predict IVSAWS path losses.

4.5.1 ELR capabilities overview.

The ELR model has the embedded capability to differentiate among three modes of electromagnetic propagation: (1) line-of-sight, (2) diffraction, and (3) scattering. By computing the distance from a sited unit to the horizon and computing the angle of the transmission ray from that unit to a normal line at the horizon, the ELR program computes parameters for making a determination of the mode of electromagnetic wave propagation which has the smallest signal attenuation. This continuous curve of attenuation as a function of distance represents a reference attenuation to be expected at each distance over homogeneous terrain within the specified area.

If the terrain varies widely in character within the desired area of profile, then greater variability about this median must be expected. Also, if the antennas are sited in extreme, rather than typical locations, the calculated attenuation will not represent the median of measurements. Terrain irregularities are represented by a single terrain parameter, Ah, which represents terrain roughness as a statistical variation in terrain height. This parameter is used to determine the median terrain effects in the specified area.

4.5.2 General description.

An in-depth discussion of the Longley-Rice attenuation model is beyond the scope of this report. For more details see [9]. The following description provides a summary of the processing and parameters that characterize the model as they apply to IVSAWS communication links.

The area mode of the ELR Propagation Attenuation Model depends on a minimum number of parameters. It requires the system parameters: frequency, antenna heights, and distance; also, environmental parameters such as atmospheric characteristics; and finally a terrain parameter Ah.

Given these inputs, the propagation loss subroutines first computer referenced attenuation, which is a continuous function of distance. This function is defined in three regions, called the line-of-sight, diffraction, and forward scatter regions. In the line-of-sight region, the bulge of the earth does not interrupt the direct radio ray, but hills and other obstructions may do so. In other words, this region extends to the smooth earth horizon, which may be further from the transmitter than the actual horizon. In the diffraction region the reference attenuation is a weighted average of knife-edge and smooth-earth diffraction. The weight used here is a function of terrain type, radio frequency, and antenna heights. And finally, at greater distances, the reference attenuation is based on forward scatter computations.

The ERL model does not include the effects of suburban or urban surroundings. To compensate, urban and suburban corrections were added to the free space path loss and terrain loss predictions. The power (P_r) of a received signal can be expressed as

$$P_r = P_{r0}\,(r / 1\text{ mile})^{-\gamma}\,(f / 900\text{ MHz})^{-n}\,\alpha_0$$

where P_{r0} is the power one mile away from the emitter, r is distance in miles, γ is the path loss slope, f is frequency in MHz, and α_0 accounts for the effects of transmitter power, transmitter and receiver antenna heights, and transmitter and receiver antenna gains. Experimental results show that, for frequencies below 450 MHz, n does not vary significantly and can be considered a constant. The excess urban/suburban path loss with respect to open (rural) terrain can be found by normalizing the urban and suburban P_r with respect to the rural value.

$$\frac{P_{r\,(\text{urban/suburban})}}{P_{r\,(\text{rural})}} = \frac{P_{r0\,(\text{urban/suburban})}\,(r / 1\text{ mile})^{-\gamma\,(\text{urban/suburban})}\,(f / 900\text{ MHz})^{-n}\,\alpha_0}{P_{r0\,(\text{rural})}\,(r / 1\text{ mile})^{-\gamma\,(\text{rural})}\,(f / 900\text{ MHz})^{-n}\,\alpha_0}$$

$$\frac{P_{r\,(\text{urban/suburban})}}{P_{r\,(\text{rural})}} = \frac{P_{r0\,(\text{urban/suburban})}\,(r / 1\text{ mile})^{-\gamma\,(\text{urban/suburban})}}{P_{r0\,(\text{rural})}\,(r / 1\text{ mile})^{-\gamma\,(\text{rural})}}$$

Substituting values derived from empirical data [5] yields the following urban and suburban path loss corrections:

$$\frac{P_r\ (\text{urban})}{P_r\ (\text{rural})} = \frac{4.0 \times 10^{-7}\ \text{mwatt}\ (r/1.6\ \text{km})^{-4.31}}{1.3 \times 10^{-5}\ \text{mwatt}\ (r/1.6\ \text{km})^{-4.35}} \cong -15\ \text{dBm} \qquad (4.5.2.1)$$

$$\frac{P_r\ (\text{suburban})}{P_r\ (\text{rural})} = \frac{6.8 \times 10^{-7}\ \text{mwatt}\ (r/1.6\text{km})^{-3.84}}{1.3 \times 10^{-5}\ \text{mwatt}\ (r/1.6\ \text{km})^{-4.35}} \cong -13\ \text{dBm} + 5\log(r/1.6\ \text{km}) \qquad (4.5.2.2)$$

With respect to communication in an open area, the effect of the excess urban/suburban path loss is reduced communication range in urban and suburban environments due to a limited IVSAWS transmitter ERP. This compounds reduced range due to higher noise levels.

4.5.3 Input parameters.

The ELR model requires input of system and environmental parameters, which are described in this section. Table 4.5.3-1 lists the values used to predict path losses over IVSAWS communication links.

The following three system parameters must be supplied:

Frequency, f, in MHz -- The model is designed for a range of values from 20 to 20,000 MHz.

Structural Antenna Heights, h_{e1} and h_{e2} in meters -- The effective height of each antenna above its immediate foreground. This is usually the height of the radiation center above ground; however, it may include the height of a building or cliff, if the antenna is near the edge of a roof or a steep hill. Structural antenna heights are limited to the range of 1 meter to 3000 meters.

Unit Position/Locations, X and Y in degrees latitude and longitude --The distance, d, separating units is computed using the unit position/location and absolute height above sea level (terrain height plus antenna height). Distance is treated as a variable in the ELR model which is designed to operate in the range of 0.5 Km to 1000 Km. The lower limit is to avoid computing so-called "near field" effects. The upper limit is beyond usable conditions. Over highly irregular terrain, calculated values of transmission loss for distances from 0.5 to 5 Km are usually less reliable than those for greater distances. This is largely due to the difficulty in predicting the mixture of line-of-sight and transhorizon paths at short ranges.

The environmental input parameters are:

Terrain Parameter, Ah in meters -- This single parameter is used to characterize terrain irregularity when operating in the area mode. The Ah is the interdecile range of terrain heights above and below a straight line fitted to elevations above sea level at fixed distances.

Surface Refractivity Ns in N-units -- The model uses the minimum monthly mean value of surface refractivity. The computations are not highly sensitive to changes in Ns. Except for the longer paths, 100 Km or more in length, differences of 5 or 10 N-units cause less than a decibel difference in the calculated attenuation. The refractive index gradient is used to predict a long-term median value of transmission loss. This surface gradient largely determines the amount a radio ray is bent, or refracted, as it passes through the atmosphere. In this model, an “effective” earth’s radius, a, is defined as a function of the surface refractivity gradient or of the mean surface refractivity, Ns. This permits a straight ray assumption, within the first kilometer above the earth’s
surface. At very much higher elevations, the effective earth’s radius assumption overcorrects for the amount the ray is refracted and may lead to serious errors. Minimum monthly mean values of Ns are used to characterize reference atmospheric conditions. Since such values are less apt to be influenced by temporary anomalies such as superrefraction or subrefraction; they provide a rather stable reference.

Climate a code type -- To calculate variability in time, a climate type is indicated, which is identified by the numbers 1 to 7. These numbers correspond to the seven radio climates defined by the CCIR (1974B). If the climate is unspecified, Climate 5, the continental temperate value, is assumed. For short paths like those in a land-mobile service, the variability in time is much less than that from path-to-path.

The remaining input parameters are the polarization of the radiated waves and the electrical ground constants. At frequencies above 100 MHz for propagation over land, these parameters have little significance.

4.5.4 Terrain parameter.

In VHF and UHF propagation over irregular terrain near the earth’s surface, a number of parameters are important. For transhorizon paths the most important of these parameters appears to be the angular distance, **2**. For within-the-horizon paths the clearance of a radio ray above the terrain between terminals is one of the most important factors.

In considering terrain effects, only the terrain along the great circle path between terminals is needed. The angular distance, **2** , is then defined as the angle in the great circle plane between the radio horizon rays between the transmitting and the receiving antennas. The angular distance, **2** , is positive for transhorizon paths, zero at grazing incidence, and negative for line-of-sight paths.

In the area mode, specific path profiles are not available, and these terrain parameters must be estimated from knowledge of the statistical character of the terrain involved In a study of a large number of terrain profiles, the interdecile range, Ah(d), of terrain above and below a straight line fitted by least squares to the altitudes above sea level was calculated. It was observed that for a large number of profiles of different lengths in a given area the median values of Ah(d) increase with path length to an asymptotic value, Ah. This value was then used to characterize terrain. At any desired distance, d, the value of Ah(d) is determined by:

$$Ah(d) = Ah\ (1 - 0.8\exp(-0.02d))\ \text{meters} \qquad (4.5.4.1)$$

where Ah(d) and Ah are expressed in meters, and d is in kilometers.

It should be noted that this definition of Ah differs from the one used by the International Radio Consultative Committee and the FCC. Their definition of Ah is the interdecile range of elevations above sea level in the range of 10 to 50 Km from the transmitter. In the homogeneous terrain, the values of Ah(d) measured over a large number of paths agree with those calculated using the relationship in 4.5.4.1. Where the terrain is not homogeneous, a wide scatter of values occurs, and the estimated value of Ah(d) may not represent a true median at each distance. In such circumstances, different sectors of an area may be considered and a Ah(d) predicted for each sector. An example of this would be an area that includes plains, foothills, and mountains.

In this ELR area mode a uniformly homogeneous area is assumed and therefore a single value of Ah is input to the program A major problem is that the area of interest is rarely homogeneously irregular. In such a situation judgment must be exercised in selecting paths that will be representative of those that will actually be used in a proposed deployment. For example, if the desired paths will always be along or across valleys, do not choose terrain profiles that cross the highest mountains.

Some qualitative descriptions of terrain and associated ranges of Ah are listed below.

Terrain Description	Ah (meters)
Water or very smooth plains	0 - 5
Smooth plains	5 - 20
Slightly rolling plains	20-40
Rolling plains	40 - 80
Hills	80 - 150
Mountains	150 - 300
Rugged mountains	300-700
Extremely rugged mountains	>700

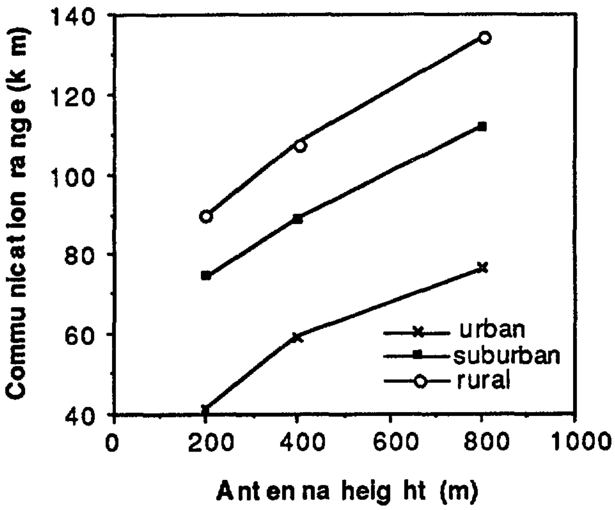
The area mode depends heavily on the parameter Ah. Whether or not a better estimate is needed, based on computed values, depends on the sensitivity of the predicted values of transmission loss to changes in Ah. This sensitivity is quite complicated, depending on the value of Ah itself, antenna heights, distance range, siting criteria, and radio frequency.

4.5.5 Communication range.

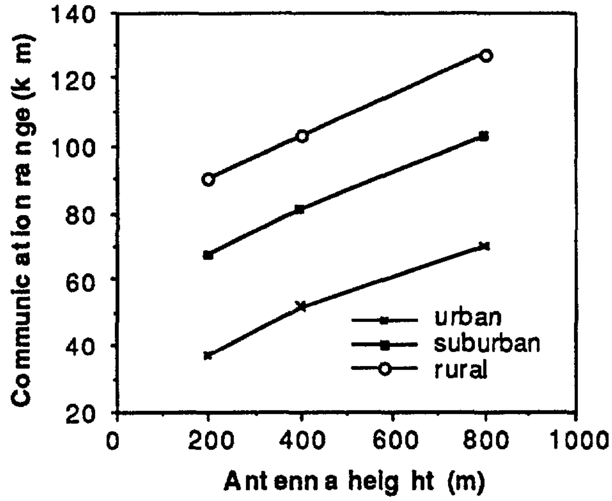
The HAC ELR model was executed repetitively in order to determine base station and mobile unit communication ranges in urban, suburban and rural settings. Excess urban and suburban path losses (given by (4.5.2.1) and (4.5.2.1)) were added to the calculated free space and terrain path loss values. The transmitter and receiver positions where adjusted until and 11 dB Eb/N_0 was achieved for each combination of setting, terrain, and transmitter type. Table 4.5.5-l lists the parameter values selected for the model. Figure 4.5.5-l shows the predicted IVSAWS base station and mobile unit communication ranges.

Table 4.5.5- 1 Extended Longley-Rice model parameters.

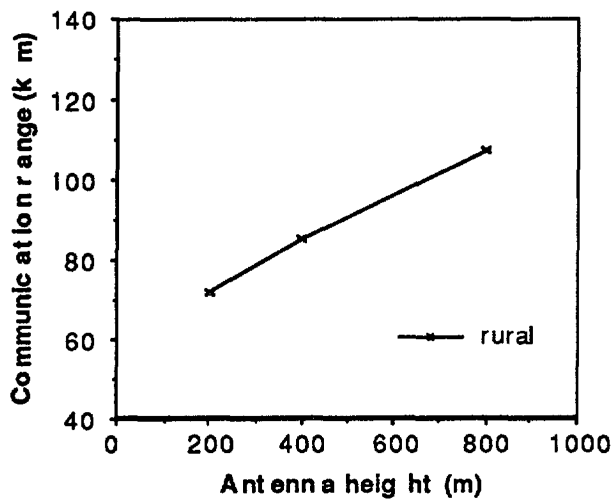
Climate code	continental temperate	
Ground conductivity	0.13 x 10-2	Siemens/meter
Ground dielectric constant	7	(average ground)
Surface refractivity	301	N-units
Effective antenna height		
base station transmitter	200 - 800	meters
mobile transmitter	1.5	meters
mobile receiver	1.5	meters
Radiated power		
base station transmitter	500	Watts
mobile transmitter	50	Watts
Antenna gain (maximum)		
base station transmitter	6	dB
mobile transmitter	0	dB
mobile receiver	0	dB
Antenna type		
base station transmitter	l/2 wave dipole	
mobile transmitter	l/4 wave whip	
mobile receiver	l/4 wave whip	
Carrier frequency	221	MHz
System altitude	300	meters
Terrain roughness		
plains	30	meters
hills	90	meters
mountains	200	meters



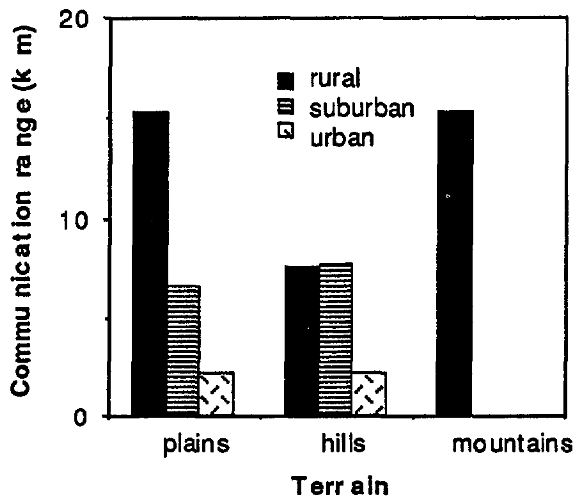
(a) Base station communication range,
terrain roughness = 30 meters (plains).



(b) Base station communication range,
terrain roughness = 90 meters (hills).



(c) Base station communication range,
terrain roughness = 200 meters (mountains).



(d) Mobile unit communication range.

Figure 4.5.5-1. IVSAWS base station and mobile unit communication range as a function of setting and terrain roughness. Base station antenna heights given are above average terrain elevation. Mobile unit antenna height is fixed at 1.5 meters.

5.0 FEC performance.

Table 5-1 lists the Eb/No required to maintain a 1 x 10^{-5} decoder output BER using different half-rate coding schemes.

Table 5.1. Performance of selected half-rate codes.

Coding scheme	Average Eb/No (dB) required for Pb(e) = 10^{-5} (DQPSK)
Constraint length 7 convolutional encoding Soft decision Viterbi decoding (8-level quantization)	7.5
Golay (24,12)	10
Reed-Solomon (31,15,8)	11
Hamming (7,4)	11.4
BCH (127,64,10)	13

Due to its superior performance, a half-rate constraint-length seven convolutional code was selected. The additional coding gain (e.g., 3 dB with respect to Golay) will extend IVSAWS communication range beyond that achievable using the other codes listed. The soft-decision decoding is more complex than the other codes examined, however, at the IVSAWS data rate (6075 bps), software implementation is possible using standard processors. Additionally, the performance of the Viterbi algorithm is known to degrade significantly in the presence of burst errors. Thus, interleaving is recommended in order to reduce the impact of burst errors introduced by Rayleigh and Rician fading.

6.0 Interleaver performance.

The IVSAWS waveform employs uniform interleaving. The 26 x 14 bit deinterleaver will distribute a burst error up to 7 symbols (14 bits) long uniformly throughout a 364 bit message (BER = 3.8 x 10^{-2}) Since the soft decision Viterbi decoder performs poorly at BERs greater than 5 x 10^{-2}, the interleaver is roughly matched to the decoder. That is, increasing the depth of the interleaver (e.g., 19 x 19) will not improve BER performance. The 26 x 14 structure was selected since the IVSAWS message is actually 366 bits long the two “extra” bits can supported by extending a single column by two bits. Other structures seemed to lead to awkward implementations.

Figure 2.4-l shows that, at low vehicle speeds, Rayleigh fading can destroy an entire message, not just a few bits of a message. Under these circumstances, interleaving will not improve performance unless data spanning several messages is interleaved. For mobile IVSAWS units, this is not a viable solution since transmissions only occur once every 3 seconds, interleaving several messages would extend the message decoding over a period of time longer than the recommended driver alert distance interval. Adaptive channel equalization is a better solution for mobile broadcasts exposed to Rayleigh fading.

Even without multi-message interleaving, interleaving will improve Viterbi decoder performance under Rician fading conditions since the average fade duration is less than that which occurs during Rayleigh fading. Under Rician fading the average fade duration is

7.0 Base station diversity.

A combination of frequency and time diversity is used to assure that a sufficient number of base station transmitters can operate in the same area of communication coverage without introducing message collisions. On each of the two IVSAWS operating frequencies, base stations are allocated two of the three available slots, resulting in a total of four noninterfering channels. Figure 7-1 shows than four channels are sufficient, even over smooth terrain in which no geographical structures are present to attenuate interfering signals, provided the co-channel signal to interference ratio (S/I) is above the threshold required for acceptable performance.

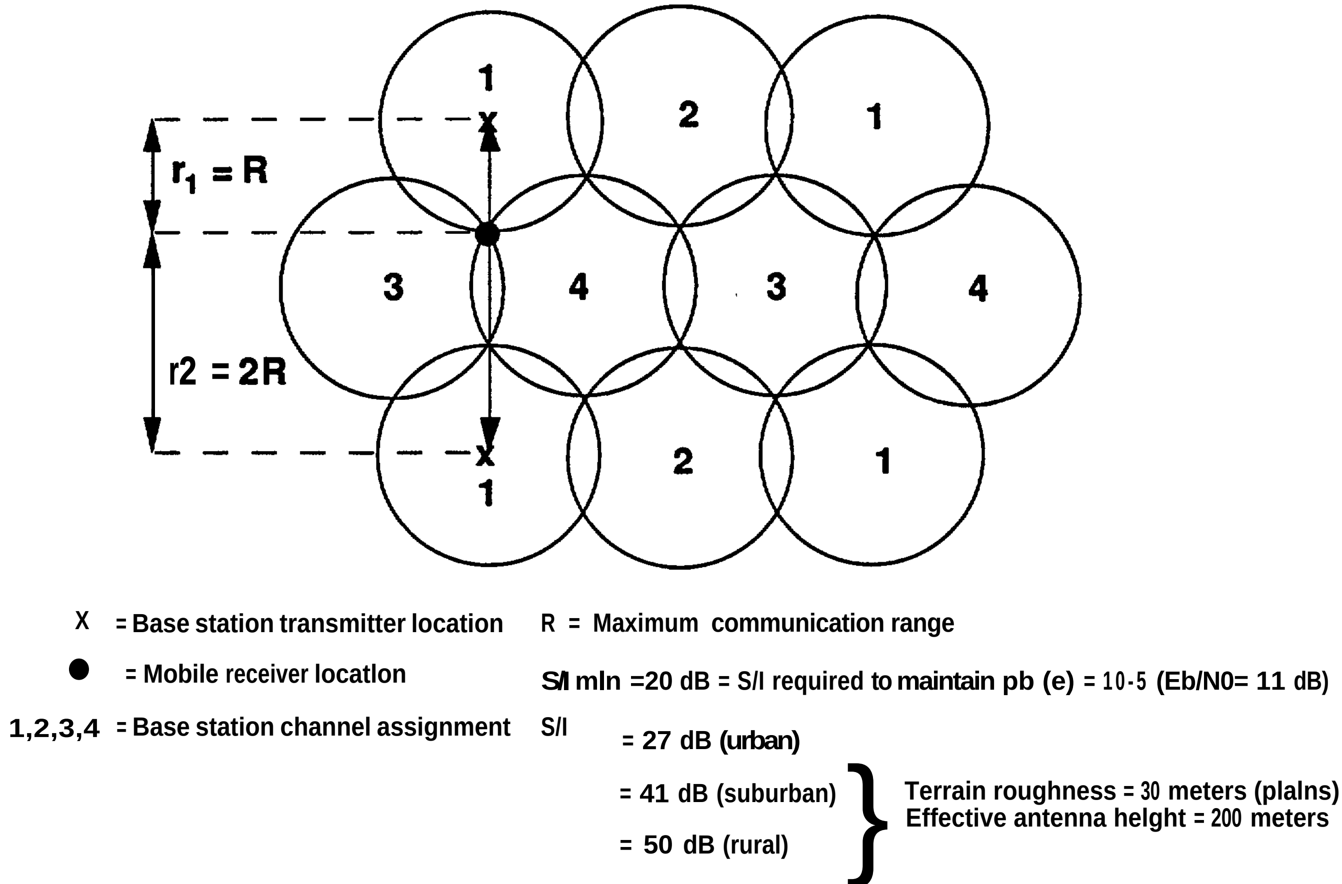


Figure 7-1. Base station lavout over smooth terrain. Four channels are sufficient to provide continuous coverage while maintaining an accentable co-channel signal-to-interference (S/I) margin.

In order to maintain a BER of 1 x 10-5, the signal-to-noise interference ratio (S/I), should be greater than 20 dB[Bennedetto]. HAC ELR model results indicate that when a receiver is at the edge of a base station's communication range, under worst case conditions, the nearest co-channel base station transmitter signal is 27 dB lower than the desired signal (S/I = 27 dB). Worst case corresponds to transmission over plains in an urban environment. As communication range increases in suburban and rural environments, the base station transmitters can be placed farther apart and the curvature of the earth begins to attenuate the interfering signal due to the line-of-sight nature of 220 MHz communication.

It should be noted that more than one co-channel base station has the potential of interfering with the desired signal. However, the next nearest co-channel base station is almost twice as far away and the resulting interference level can be ignored, again due to earth curvature effects.

[FHWA R-35]

8.0 Mobile unit diversity.

Each active mobile unit transmits an alert once every three frames using a Slotted ALOHA protocol. At most, ten mobile alerts can be broadcast each frame. Thus, every three seconds, the transmitter randomly selects one of 30 available alert transmission periods. Occasionally, two or more mobile transmitters within communication range of the same receiver will select the same transmission time and frequency, resulting in the reception of a garbled message. The waveform design must be robust enough such that, with a reasonable number of transmitters within communication range of the same receiver, the probability of collision is within limits. Two scenarios were considered:

Scenario 1: A single roadway hazard event occurs (e.g., accident site) with multiple IVSAWS-equipped emergency vehicles responding. All vehicles are parked near the hazard with transmitters activated. In this situation it is sufficient that a single alert be broadcast without collision once every six seconds (six seconds corresponds to the minimum driver alert distance for vehicles travelling at high speeds). Assuming 20 active transmitters, what is the probability that at least one message is transmitted without collision during a three frame segment? Simulation results show that the probability is greater than 0.9999.

The simulation results show that the IVSAWS Slotted ALOHA structure can easily support situations in which multiple emergency vehicles have responded to the same event, It should be noted that this scenario is not expected to be a normal IVSAWS operational mode. Vehicles are expected to be equipped with devices which automatically deactivate IVSAWS transmitters as the response personnel exit their vehicles. Prior to departure, the response personnel will call the hazard location and description into an IVSAWS operations center (IOC) which will then project a single warning zone around the hazard site via a base station transmitter. This process will minimize driver irritation caused by the reception a multiple alerts from a single hazard event.

Scenario 2: Five distinct emergency response vehicles are in transit to five different events within communication range of the same receiver. What is the probability of all five vehicles transmitting an alert, without collision, during the same three segment? The probability is 0.70. What is the probability of a given vehicle transmitting a message that collides with the transmission from one or more other vehicles during the same three frame segment? The probability is 0.13. What is the probability of a given vehicle transmitting a message that collides with the transmission from one or more other vehicles during two **successive** three frame segments? The probability is 0.02

The simulation results show that with high probability (0.98) each vehicle will transmit an alert without collision every six seconds. The analysis is worst case in the sense it assumes message collisions are completely destructive. However, in many cases the transmission from a vehicle which is significantly closer to a receiver than other transmitters that are within communication range will dominate the collision process. In these cases, the alert from the nearest vehicle will be not be garbled. Moving hazards which are closer to a given vehicle are presumably more threatening.

9.0 Conclusion.

The performance analysis shows that the IVSAWS square-root raised-cosine B/4-shifted DQPSK waveform operating at 220 MHz using differentially-coherent demodulation can meet the target performance (BER = 1 x 10-5) while providing continental coverage for both base station and mobile transmitters. Cost effective modem implementation is expected since devices of higher complexity (e.g., digital cellular telephones) are expected to sell below the $400 level once initial market penetration is achieved. Other radio components such as amplifiers are available off the shelf.

Four issues have been identified as significant and are presented below in order of importance:

1. Cost effective system implementation depends upon the affordable construction of a network of base station transmitters. Communication range will therefore have a major impact on system cost since the required base station density decreases by seven if base station communication range is increased by 2.5 (over rural plains). In a rural environment, over plains, the performance analysis projects that seven base stations will be required to provide continuous coverage over a 450 km (280 mile) diameter circle if the antennas are elevated 200 meters above the average terrain. Using towers to increase antenna elevation significantly extends communication range, however, this approach has its limitations due to the cost of erecting tall towers. Placing smaller towers on hilltops will be more cost effective.

   A better solution to extending communication range would be to transmit the IVSAWS signal at a lower frequency. Lower frequencies will exhibit less transhorizon path attenuation. If the FHWA secures a nationwide channel at a lower frequency, it is recommended that IVSAWS operation be shifted. The specified waveform can be transported to any operating frequency which supports a channel with at least 4 KHz of usable bandwidth. At the present time, however, the secured 220 -222 MHz channels appear to be the only viable option.

2. The communication ranges predicted by the HAC ELR model depend upon an ERP above the limits specified in the FCC Rules to Provide for the Use of the 220-222 MHz Band by the Private Land Mobile Radio Service. An ERP of 500 Watts at all antenna HAATs is assumed. While an exemption to the specified limits is probable, it implies more sophisticated baseband and/or RF filtering in order to contain spectral emissions on adjacent channels to levels which would occur if the specified ERP limits were followed.

3. Rayleigh fading significantly reduces over the horizon communication range. Since fades will typically span tens to hundreds of bits at levels 10 - 20 dB below the average signal level, adaptive channel equalization has the potential to significantly extend communication range. It is recommended that equalization be evaluated I in the field in order f to measure its merit. a significant increase in communication range can be achieved, the use of equalization should be incorporated into the waveform standard by direct specification or by the adoption of performance standards which imply its use.

4. The performance of the mobile transmitter Slotted Aloha protocol shows that, in a five transmitter environment with all transmitters in communication range of the same target receiver, the probability that any given mobile unit will transmit an alert without collision every six seconds is 0.98. This scenario needs to be monitored to ensure that it represents an upper bound. It is at least feasible that more than five emergency vehicles could be in transit to the same event at the same time, each representing a distinct and separate hazard. For the purpose of this study it was assumed that the probability of having six or more mobile units simultaneously in transit within the same communication coverage area is small.

10.0 References.

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